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PREFACE

TO

THE FIRST EDITION.

THE following pages are intended to convey to the reader a plain, clear, and concise account of the most important phenomena of the science of Electro-magnetism, or Electro-dynamics; a science which ever since its discovery has engaged the attention of many eminently learned and scientific men in every civilized state.

This science is of great importance to the philosopher and to the world; as it will probably lead to a more intimate, if not a perfect knowledge of Electricity and Magnetism, and thus be the means of ascertaining that Electricity and Magnetism are either distinct and separate principles, or that they are one and the same principle differently modified.

Several valuable papers on the subject, by Mr. Faraday, of the Royal Institution, have been published in the *Quarterly Journal of Science, Literature, and Art;* and in the *Annals of Philosophy*. The subject has been treated of in an Appendix to Mr. Barlow's *Essay on Magnetic Attractions;* and there is also an article in the *Encyclopedia Metropolitana* on this subject. No distinct work on Electro-magnetism had appeared in England until Professor Cumming published a translation of M. J. F. Demonferrand's *Manuel d'Electricité Dynamique*. But as many persons may wish to be acquainted with the subject who, from not being familiar with mathematical expressions and formulæ, would have difficulty in perusing Professor Cumming's work, this Popular Sketch has been compiled; and to assist the same class of inquirers, and in the hope of spreading over a wider field a more general knowledge of the parent sciences, Electricity and Magnetism, an outline of these sciences has been carefully traced.

PREFACE

TO

THE SECOND EDITION.

In the year 1828, the late Mr. Francis Watkins published his work entitled *A Popular Sketch of Electro-dynamics*. The important discoveries of Oërsted, Ampère, Davy, Arago, Faraday, and others were then known only to the few; hence the appearance of such a work, gathering together the isolated facts scattered over the philosophical journals of the period, was not only of great interest, but of much practical value.

Twenty-eight years have elapsed since that work first appeared, during which period many of the views then entertained have undergone an important change: new facts have been discovered, new instruments invented, and old ones improved and simplified. But this is not the only change which has occurred; for then but few of the master-minds of the age were engaged in the investigation of this novel and intricate branch of physical science, while now to every one of that date we number thousands at the present time.

When the treatise of Mr. Watkins was first published, the only existing work in the language was the translation, by Professor Cumming, of M. Demonferrand's *Manuel d'Electricité Dynamique*—a work of great value, but of too technical a character for popular information. Numerous other works have since appeared in which this subject forms a part, and none of greater value than the important *Experimental Researches* of Dr. Faraday, in three volumes: nevertheless, but few books have been written solely on this subject of a popular nature. With this feeling, Messrs. Elliott, the successors of the late firm of Watkins and Hill, have determined upon issuing a new edition of the book of 1828. The Editor's task has been one of no little difficulty; for, while being most anxious to retain as much of the original as would be consistent with the advanced state of the science, yet the multitude of new facts, instruments, and applications have made it necessary to introduce so much new matter, that it makes it a new work rather than a new edition. Nothing of an experimental nature that could interest the reader has been omitted; while the additions, it is hoped, will be found both useful and interesting to the tyro in this branch of that extensive range of phenomena now included under the head of Electricity.

G. H. B.

London, September, 1856.

A POPULAR SKETCH

OF

ELECTRO-MAGNETISM.

ELECTRICITY.

1. ELECTRICITY is generally regarded as an imponderable force,* which is made cognizable to our senses, either by friction, by pressure, by contact, or other mechanical actions (as in the exit of high-pressure steam through small apertures), by chemical action, by magnetism, by the disturbance of the equilibrium of temperature, and by various animals.

2. When produced by mechanical action, it is commonly denominated frictional electricity; by chemical action, it is called galvanism, or voltaic electricity; by magnetism, magneto-electricity; by a disturbance of temperature, thermo-electricity; and by the last source, animal or vital electricity.

3. It is our intention in this slight sketch to treat only of the effects presented by electricity, and not to enter into any theoretical disquisition as to the primary cause of electrical excitation: it is enough for our purpose to know that such a principle exists, possessing certain properties, and it is only to those properties that we shall direct attention; nevertheless, there is, at the very outset of our investigation, one

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* "The position which I seek to establish is, that the various affections of matter which constitute the main objects of experimental physics, viz., heat, light, electricity, magnetism, chemical affinity, and motion, are all correlative, or have a reciprocal dependence. That neither, taken abstractedly, can be said to be the essential or the proximate cause of the others; thus heat may mediately or immediately produce electricity, electricity may produce heat, and so of the rest, each merging itself as the force it produces becomes developed."—Grove *On the Correlation of Physical Forces*, vol. ii. page 13.

theoretical point which must not be passed over without some little explanation, viz., the two states or kinds of electricity, the effects of which will be better understood by the following experiment.

4. Let a small hollow paper cylinder be freely suspended by a piece of silk thread, Fig. 1; on presenting to it a glass tube that has been well rubbed with a dry and warm silk handkerchief, the paper cylinder will be immediately attracted, and adhere for a few moments, and then detach itself; on again presenting the glass tube to the cylinder, it will be repelled. If the cylinder be touched with the finger so as to discharge the electricity it has acquired from the tube, a repetition of the effects (attraction or repulsion) may be obtained.

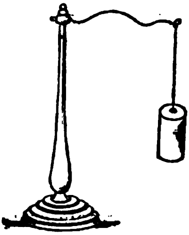
Fig. 1.

5. For the next experiment, two paper cylinders mounted as shown on Fig. 1 must be provided. If in addition to the glass tube a piece of sealing-wax be rubbed with a piece of dry warm flannel, both cylinders may be electrified by touching them, one with the sealing-wax, the other with the glass tube: on bringing the two cylinders sufficiently near, they will attract each other. If, on the contrary, they are both electrified by the wax, or by the excited glass tube, and they are brought together as before, they will be found to repel each other. These experimental facts may be rendered more evident by the following. Let the electricity be excited on the glass by friction with the silk (as before), and its electricity communicated to the cylinder, so as to produce repulsion; rub a piece of sealing-wax and bring it near to the same cylinder electrified by the glass, when, instead of repulsion, we shall find it will be attracted.

6. By these experiments, we see that there is a material distinction between electricity excited by friction on glass and on sealing-wax; in fact, that two similar but opposite forces have been developed: for the cylinder electrified and repelled by the glass, was immediately attracted by that excited by the sealing-wax.

7. To distinguish these two states or kinds of electricity, the terms positive or vitreous, negative or resinous, have been

introduced; the former applying to the electricity obtained by the excited glass, and the latter to that of the sealing-wax.

8. In order to explain the above phenomena two different hypotheses exist, commonly called the single and double fluid theories;* one being due to Franklin, of America, and the other to Du Fay, of France.

9. The Franklinic, or single fluid theory, supposes electricity to be a subtle imponderable fluid, existing in all bodies in definite quantities: hence, whatever may be the proportional quantity which any one body is thus supposed to possess, so long as this remains undisturbed, the body is regarded as being in an un-electrified or neutral state. But when friction or some other force is applied, this quantity may be diminished or increased; if an increase is produced, then the body is said to be positively electrified, or plus, and negatively electrified, or minus, if the quantity should be diminished.

10. The double fluid theory supposes the existence in all substances of two electric fluids of opposite characters in equal quantities existing in a state of equilibrium; by friction, a decomposition of the two fluids is effected, the rubbing body acquiring an excess of one fluid, and the body rubbed an excess of the other: these Du Fay called resinous and vitreous.

11. In illustration of these opposite views of the phenomenon of electrical excitation, the experiments given above will afford us an example. Thus, the Franklinic hypothesis supposes that when the glass tube is rubbed with the silk, the latter parts with a portion of its natural quantity of electricity to the glass, which then becomes positively electrified, the silk, on the contrary, being left in the negative or minus state. By the double fluid theory, the rubbing of the glass by the silk has effected a separation of the two fluids,

---

* It will be observed that we shall frequently have to employ the terms "electric fluid" and currents of electricity. But it must be remembered that these expressions are only made use of for convenience; for we know not whether electricity be material or a peculiar condition of matter, nor have we any proof of the existence of any current; and all that is intended to be understood is, that the effects presented are similar to those which would take place if a fluid subjected to certain assigned laws of action really existed.

the rubber taking, we will suppose, the resinous, and the glass the vitreous; both bodies having become electrified, one by an excess of the resinous, and the other by an excess of the vitreous electricities.

12. Whichever theory may be adopted, the terms are convertible; thus, positive corresponds to vitreous, and negative to resinous. It is, however, very questionable if either theory will bear the test of inquiry when examined by the light of modern discoveries.

13. "Electricity is now regarded as a compound force, remarkable for the peculiar form of action and reaction which it exhibits. This kind of action and reaction follows the same laws of equality and opposition in its manifestation as that which is exhibited more obviously in the phenomena of mechanics. Whenever vitreous electricity is manifested at one point, a corresponding amount of resinous electricity is invariably developed in its vicinity, reacting against it, and thus enabling its presence to be recognised, although this reacting force may not be immediately perceptible." * "I think I shall not be unsupported by many who have attentively studied electrical phenomena, in viewing them as resulting, not from the action of a fluid or fluids, but as molecular polarization of ordinary matter, or as matter acting by attraction and repulsion in a definite direction."†

14. The transmission of electricity is very different in different bodies. Thus, if one of the paper cylinders, Fig. 1, be strongly electrified by contact with the excited glass rod, and it be touched by the finger or a metal rod, its electricity is immediately withdrawn; but if instead of the finger or the rod of metal we employ a stick of dry sealing-wax, its electrical condition is not in any way affected. From this it is evident that some bodies, as the metal rod or finger, admit of the passage of the electricity much more readily than the sealing-wax: the former class are termed conductors, and the latter insulators or non-conductors.

It is, however, exceedingly difficult to draw the line of demarcation, even if such exists, between a perfect conductor and a perfect insulator. The following table exhibits the order in which some of the most important substances stand

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* Dr. Miller's *Elements of Chemistry,* part i. page 279.

† Grove *On the Correlation of Physical Forces,* 2nd edit. page 48.

as regards conduction; those at the top being the best, and gradually diminishing in conducting power until we arrive at the class of non-conductors or insulators.*

CONDUCTORS.

The metals
Charcoal
Plumbago
Melted salts
Flame
Water
Fixed oil
Volatile oils
Spermaceti
Ice
Glass
Dry fur
Dry silk
Diamond
Gutta percha
Resins
Amber
Sulphur
Shell lac
Dry gases

Insulators

15. An important principle of action in connexion with all electrified bodies is the power they possess of producing, without contact, a disturbance of the electrical equilibrium in all adjacent bodies, by a process termed induction.

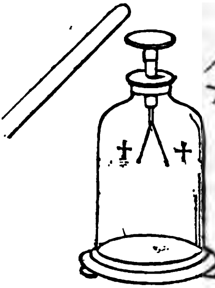

Fig. 2.

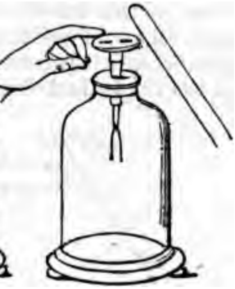

Fig. 3.

16. The following is a very simple yet instructive mode of illustrating electrical induction:—Excite a tube of glass, and bring it near, but not so as to touch the brass cap of a gold-leaf electroscope, Fig. 2, when it will be observed that the gold

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* A substance is said to be insulated when placed upon a worse conductor than itself; thus a metal rod, when mounted upon a stem of wax or glass, is insulated.

leaves instantly diverge, and remain in that condition so long as the tube is held over the cap; but that they return to their original condition on it being withdrawn. Repeat the experiment, and whilst the leaves are diverged, let the finger touch the cap, as in Fig. 3, the leaves will collapse; withdraw the finger, and immediately afterwards the glass tube and the leaves will open and remain permanently charged. If, while in this state, the excited tube is once more brought into its former position, the gold leaves will be seen to collapse.

The explanation of this experiment is generally thus stated:—On bringing the excited tube to the electroscope, it causes the negative electricity due to the cap and leaves to be accumulated on the cap, the positive being repelled, causing the leaves to diverge; on withdrawing the tube, as no electricity has passed, the equilibrium of the electroscope is instantly restored; but on touching the electroscope, while the leaves were in a divergent state, Fig. 3, the finger carried off the excess of positive electricity, when the negative electricity spread over the leaves, causing them to diverge. This explanation is given agreeably to the supposed existence of two fluids; and as this law of induction is one of extensive application and serves to explain many important phenomena, we here give another experiment, the explanation of which is based upon the single fluid theory.

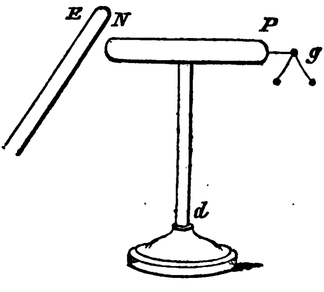

Fig. 4.

17. N P is a brass cylinder supported on a glass stem (*d*); to the end P is suspended an electrometer consisting of two small pith balls. On presenting the excited glass rod E to the

cylinder at the distance of a few inches, the pith balls instantly diverge, and again collapse on its being withdrawn. Restore the tube E to its former position, and while the pith balls are in a divergent state, touch the cylinder N P with any conducting substance, remove the conductor, and then the excited glass tube; when the pith balls again diverge, and the cylinder N P remains permanently electrified. The following is the explanation offered by the advocates of the single fluid theory:—The free electricity of the tube E repels the natural quantity of electricity of N P to the farthest extremity P, which then exhibits itself in excess by the diverging of the pith balls; the cylinder being uninsulated for the moment by touching it with any conducting substance, admits of the withdrawal of a portion of the natural quantity of electricity of the cylinder N P, the insulation of the latter being restored by the removal of the conducting substance. On withdrawing the tube E, the cylinder is left minus that portion carried off, and therefore negatively electrified.

18. Until the recent researches of Dr. Faraday, no very satisfactory explanation could be given of this very curious yet important phenomenon. The following is a condensed account of his investigations on this subject:—

"Dr. Faraday conceives electrical induction to depend on a physical action between contiguous particles, which never takes place at a distance without operating through the molecules of intervening non-conducting matter. In these intermediate particles a separation of the opposite electricities takes place, and thus become disposed in an alternate series a succession of positive or negative points or poles: this he termed a polarization of the particles, and in this way the force is transferred to a distance. Thus, if in Fig. 5 P represents a positively charged body, and *a*, *b*, *c*, *d* intermediate particles of air, or other non-conducting matter, then the action of P is transferred to a distant body, N, by the separation and electrical polarization of these particles indicated by the series of black and white hemispheres."*

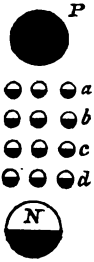

Fig. 5.

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* Sir W. S. Harris's *Rudimentary Electricity*, p. 23.

ELECTRICAL MACHINES.

19. For obtaining and exhibiting ordinary or frictional electricity, several kinds of apparatus may be employed; those most commonly used are the electrophorus, the cylinder and plate machines, and the hydro-electric apparatus of Armstrong.

20. The electrophorus, Fig. 6, the invention of Volta, is an instrument of great convenience when only small quantities of electricity are required; its operation is referrible to the phenomena of induction (17 and 18). It consists of two metallic plates, with an intervening one of resinous matter; from the lower plate passes a strip of tin foil, which is pressed down in contact with the upper surface of the resinous plate. In order to excite the resinous plate, it is simply necessary to beat the surface with the furry side of a piece of dry cat's skin; the upper metal disc is then placed upon it, which being lifted by the glass handle readily affords a spark of electricity, the quantity and power of which is of course determined by the size of the apparatus. It is not necessary to excite the resinous plate upon every spark being taken, as the effect is maintained for several hours, or even days. This apparatus furnishes the chemist in the laboratory with a very convenient substitute for the costly electrical machine.

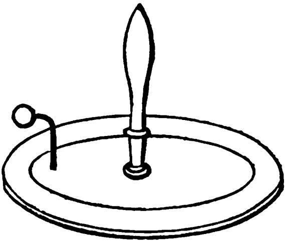
Fig. 6.

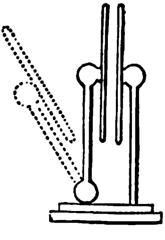
Fig. 7.

21. Upon the principle of induced electricity an apparatus is constructed, called the condenser, for detecting minute electrical disturbances. It consists of two circular brass plates, one supported by a glass

insulating stem, and the other resting upon a conducting support, jointed at the bottom. When the plate on the insulated stem is connected by means of a wire with the cap of an electroscope, very feebly excited, on the removal of the insulated plate (see figure), the electroscope renders sensible the presence of very minute electrical changes.

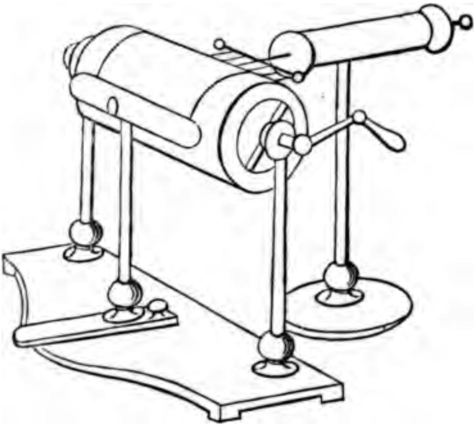

Fig. 8.

22. The cylinder Fig. 8, and the plate machines Fig. 9, are now so well understood that it is unnecessary to give any description of their construction or mode of action. Recent discoveries have, however, added to our stock of instruments the apparatus, called by its inventor, Mr. Armstrong,

23. The Hydro-electric Machine, Fig. 10, which

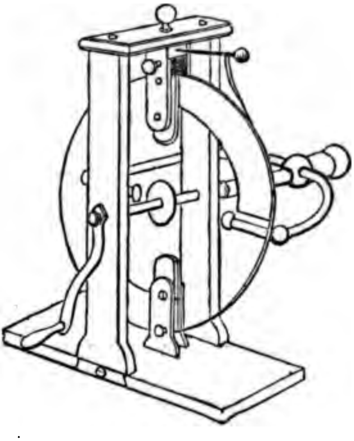

Fig. 9.

consists of a cylindrical tubular boiler, of rolled iron plate, the furnace and ash-hole being placed within the cylinder. The steam generated in the boiler is permitted to escape through one or more iron tubes, having at the point of exit a brass box, holding a small hollow cylinder of some hard wood; the steam in its passage through these pipes suffers a partial condensation, water being deposited. The friction to which this water is subjected, by the elastic force of the steam in its exit through the hollow plug or cylinder of wood, is commonly regarded as being the primary cause of the production of the electricity here obtained.

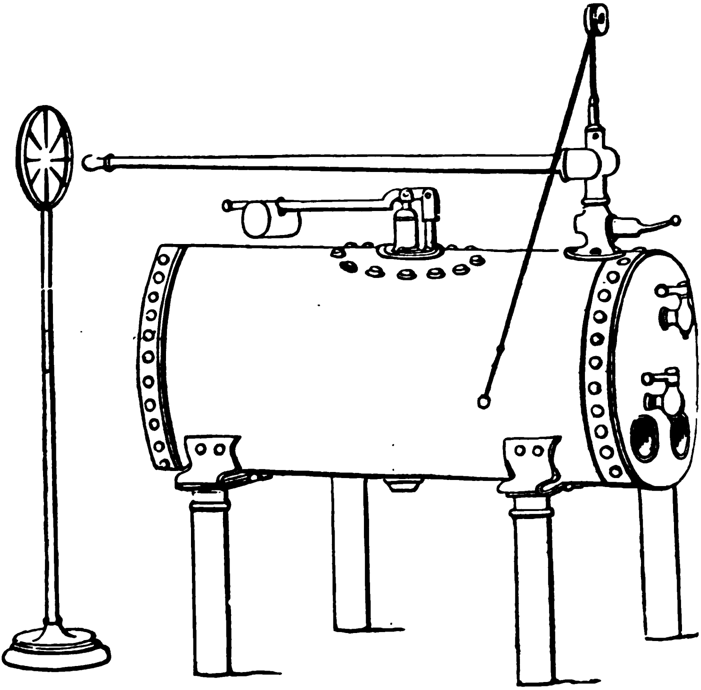

Fig. 10.

VOLTAIC APPARATUS.

We now pass to the consideration of that peculiar condition of electricity called Voltaic, after the celebrated Italian philosopher Volta, who found that when two discs of dissimilar metals were placed in contact, on their separation they exhibited evident signs of being in opposite electrical states, from which fact he was led to the construction of an instrument now commonly named after him, viz.:

24. The Voltaic Pile, Fig. 11, consists in placing dissimilar metals, as zinc and copper, or zinc and silver, in contact, and laying upon them a piece of flannel of the same size, moistened with salt and water, and on that another pair of plates, then a piece of moistened flannel, and so on, the number of the alternations depending on the pleasure of the experimentalist and the power required. The relative position of each pair must be preserved throughout the whole series;* that metal which is undermost in the first combination must be also undermost in the last. For the convenience of experiment the discs are now usually soldered together, and when piled are supported by three upright pieces of wood, as shown in the figure.

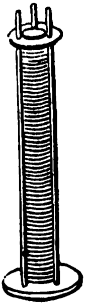
Fig. 11.

The Voltaic Battery.—The method of arrangement, the chemical character of the metallic plates, and also the exciting fluids employed, are susceptible of considerable variety; hence the different forms of batteries in use some years back, as Cruickshank's (Fig. 12), consisting of a series of plates of zinc and copper soldered together, and cemented in regular order in grooves made in the sides of a mahogany trough, and those of Babbington, Wollaston, Hare, &c. &c., which it is unnecessary to describe, as all of them are now nearly out of use, except

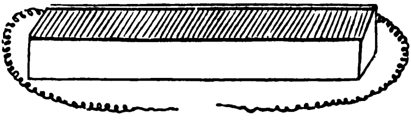
Fig. 12.

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* A fundamental law in every voltaic arrangement.

in certain particular operations, having been superseded by instruments of greater power and continuity of action, as those of Daniel, Grove, Smee, Bunsen, &c.

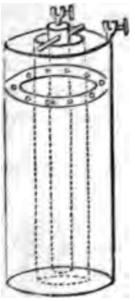

Fig. 13.

25. Daniel's Battery (Fig. 13) consists of a hollow cylinder of copper, closed at the bottom; within this is placed a porous earthenware tube or canvas bag, in the centre of which is supported a rod of cast zinc: sulphate of copper in solution with one-tenth of its volume of sulphuric acid is the liquid employed in contact with the copper cylinder, while dilute sulphuric acid alone is used in contact with the zinc. This form of battery is extremely useful where a steady current is desired for several hours, in which case it is necessary to keep up the strength of the sulphate of copper by adding crystals of this salt.

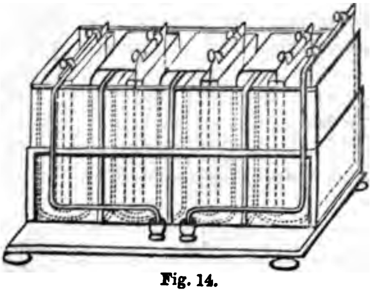

Fig. 14.

26. Grove's Battery (Fig. 14) far exceeds in power all other voltaic combinations, and its action, when the acid employed is pure, is uniform for some time. The arrangement consists of sheets of platina foil, placed in parallelopiped porous cells, filled with strong nitric acid, surrounded on the outside by a double amalgamated zinc plate, placed in a stoneware trough, in which is poured a mixture of one of sulphuric and eight to ten of water; a set of four cells, consisting of sheet platina plates, 5 inches by 2¼ inches, liberates in one minute eight cubic inches of the mixed gases by the voltameter. This battery is admirably adapted for the purpose of actuating electro-magnetic motive machines.

27. Smee's Battery (Fig. 15).—The advantages offered by this battery are considerable; for, with only one acid solution and no porous diaphragm, its action is continuous for several hours: the negative or conducting plate of this arrangement *is made of* platinized silver foil, the deposit of platina being *effected by the electrotype* process. The platinized plate is

fixed in the centre of a wooden frame, which is surrounded by the double plates of amalgamated zinc, as in the old form of Wollaston, dilute sulphuric acid being employed as the exciting agent. This battery is now extensively employed in carrying on the various processes of the electro-deposition of metals.

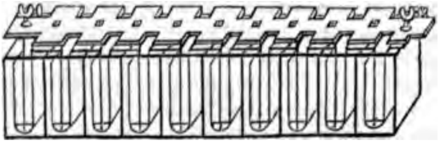

Fig. 15.

28. Bunsen's Battery (Fig. 16).—This differs from Grove's simply in charcoal, or a kind of hard coke or coal carbon, being substituted for the platina, the acids employed being the same. Bunsen's battery, although extensively employed on the Continent, is but seldom used in this country.

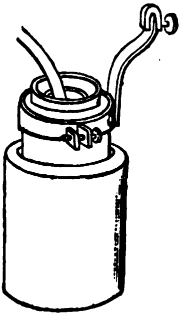

Fig. 16.

29. Grove's Gas Battery (Fig. 17).—This apparatus, although never employed for experimental purposes as a source of electrical power, is nevertheless exceedingly interesting as an agent of philosophical research. It consists of a series of separate vessels holding dilute sulphuric acid, with pairs of glass tubes sealed at the top containing strips of platinum, when the tubes in each are respectively charged, one with oxygen and the other with hydrogen.* The action of the gas

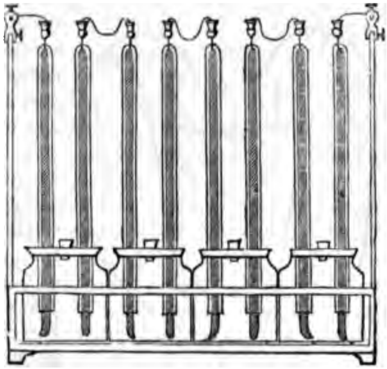

Fig. 17.

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* Art. "Electricity," *Lardner's* Cyclopœdia, vol. ii. p. 345.

battery is associated with a synthetical effect by which the gases are consumed and water is produced. A particle of oxygen, for instance, when the circuit is closed, unites with the equivalent of hydrogen in the particle of water in contact with it; the oxygen of this particle of water unites with the hydrogen of the next particle, and so on to the end of the series.

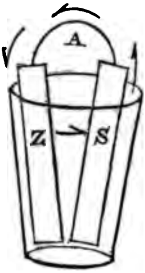

Fig. 18.

30. Before quitting the subject of the voltaic battery, it may not be uninteresting to notice the laws governing the direction of the electric current in a simple and compound circle, and also to explain certain terms which have been introduced in the science since the first edition of this work was published. A simple or single voltaic circuit, or, as it is sometimes expressed, a single pair of plates, consists, as shown in Fig. 18, of two metals, as zinc and silver, or zinc and copper, in which the chemical action is established, either by one acid, as in Smee's battery, or by two, as in Grove's or Bunsen's, in either case, the current sets out from the zinc through the fluid to the silver, and from the latter through the conducting wire A, back again to the zinc; hence the zinc is positive in relation to the silver through the acid, while the silver is the negative surface in reference to the former. But if the current, instead of passing direct through the metallic arc A, is made to pass through wires extending from the battery (as shown at B (Fig. 19) through the wire C D, then C becomes the positive, and D the negative pole of the battery. When several pairs of plates are united together so as to constitute a compound series, any single pair of plates is then differently situated, no longer occupying the same cell; for although still united, yet each plate is immersed in different cells: hence each cell of a compound bat-

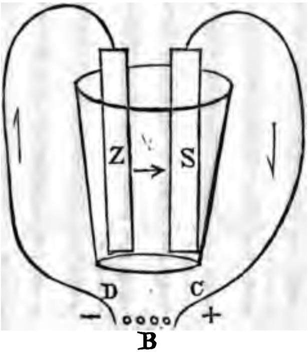

Fig. 19.

tery contains two plates, belonging to two different pairs. This will be seen at once by the mere inspection of Fig. 20.

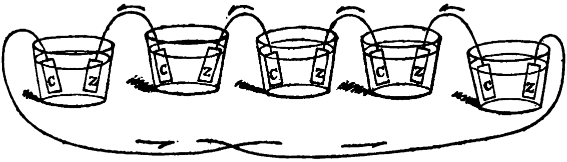

Fig. 20.

31. The following simple rule for at once ascertaining the electrical condition of the terminals of a compound battery is given by De la Rive in his *Manual*. "We must remember," he says, "that the positive pole is always at that extremity of the battery towards which the zincs of each pair are turned; the negative pole, at that towards which all the coppers are turned. If the battery, instead of being arranged in the same right line, returns upon itself, we have merely to see on which side the zincs are turned, and to remember that the positive pole is on that side."

32. In the above remarks it will be observed that the terminals of the battery are designated poles; this term pole is now (at least in this country) generally superseded by the nomenclature introduced by Dr. Faraday, who, without reference to the wires themselves, regards merely the boundaries where the current enters and makes its exit. The former he terms the anode, from ἀνὰ, up, and ὁδὸς, a way; and the latter, cathode, from κατὰ down, and ὁδὸς, a way; the terminal points being styled electrodes. Instead, therefore, of positive and negative poles, the terms anelectrode and cathelectrode are now substituted, consequently C in Fig. 19 would be the "anelectrode," and D the "cathelectrode." Again, if the two points C and D are supposed to be united by any fluid conductor (B), which by the transmission of the current suffers decomposition, such a fluid is called an "electrolyte," the evolved elements of which are termed "ions," those which present themselves at the anelectrode being called "anions," and those at the cathelectrode "cathions."

THERMO-ELECTRIC APPARATUS.

33. In the passage of electricity through conductors, if an obstruction to the flow of the current is presented in any part of the circuit, heat is developed at the point of resistance. So also any resistance to the equal transmission of heat in conducting bodies, occasions a disturbance of the electric equilibrium. The latter fact was discovered by Seebeck, in 1823, and to which effect he gave the name of thermo-electricity.

34. De la Rive[*] considers that the propagation of heat is in this case merely a means of bringing about the molecular changes that give rise to the electric manifestation, as the propagation of electricity is in its turn only a means of producing disturbances in the state of the particles, which bring on a rupture in the equilibrium of temperature.

35. If heat be applied to one end of a uniform bar of metal, that end farthest from the heat assumes a negative, and the heated end a positive electrical state. This thermo-electrical effect is found to differ with different metals. Seebeck was the first to point out that on the combination of two metals being formed into a rectangle, or any other arrangement, so as to admit of a direct circuit being established, the electric effect was very much increased, the union of bismuth and antimony was found by experiment to produce the most powerful results, and for that reason these metals are now generally employed in the construction of most thermo-electric batteries.

36. The following table exhibits a list of some of the most important metals used in thermo-electric experiments, any two of which being employed, and heat applied at the point of junction, electric currents are developed. The order of position is such, that each becomes positive to those below it; but if cold be employed, then the order is reversed:

Bismuth
Platinum
Mercury
Lead
Tin
Gold
Silver
Copper
Zinc
Iron
Antimony

37. The Thermo-electric Battery (Fig. 21) represents a single combination or pair of plates of bismuth and antimony.

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[*] De la Rive. *Electricity,* page 593.

By combining several pairs as shown at Fig. 22, we have a compound battery, which, of course, may be extended in number to any required extent. Thus, the thermo-electric massive piles of Watkins, shown in Fig. 23, consist of an association of square bismuth and antimony plates, alternately soldered together so as to form a composite battery: these are mounted in a frame, with the upper and lower junction of the metals exposed. When either ends of this arrangement are slightly elevated or depressed in regard to temperature, the electric current is established; and with the radiation of red-hot iron at one extremity and ice at the other, all the ordinary electrical phenomena may be developed.

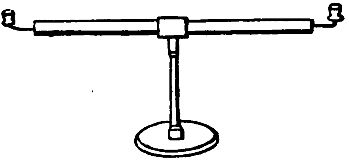

Fig. 21.

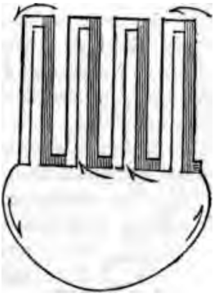

Fig. 22.

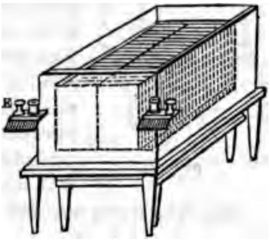

Fig. 23.

38. Fig. 24 represents the Thermo-pile of Melloni, which is constructed of very slender bars of antimony and bismuth, soldered alternately together, and arranged parallel, side by side, so that all the soldered pairs are at one end, and all the solders not pairs at the other end. This arrangement is so extremely sensitive, that it exhibits electrical effects when the disturbance of the temperature of the battery is occasioned by the mere approximation of a warm hand to either extremity.

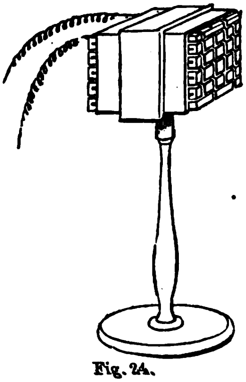

Fig. 24.

MAGNETIC APPARATUS.

39. The native magnet, or natural loadstone, is found in various parts of the globe, as Arabia, China, Bengal, Macedonia, Germany, England, &c., generally in iron mines, in which it occasionally occurs in considerable quantities, under the name of magnetic iron ore: it varies in colour from a brownish black to a deep grey. It is also found in the form of detached particles in the Isle of Skye, Fifeshire, &c., called magnetic iron sand.

40. The remarkable property which this so-called stone possesses was known to the ancients, as evinced in the writings of Thales, Pythagoras, Aristotle, and others; while its actual use for nautical purposes as a means of determining the north and south points of the globe, is by some supposed to have been known to the Chinese many centuries prior to its use in Europe. Natural magnets are now seldom employed except as objects of experimental curiosity, for which purpose they are mounted with soft iron cheeks for concentrating the magnetic power, and with a soft iron bar, called an armature (Fig. 25).

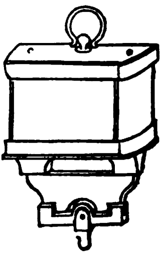
Fig. 25.

41. The term natural magnet is here employed in contradistinction to the artificial magnet, the latter being a hardened bar of steel, to which the magnetic property has been communicated. For all experimental purposes it is superior to the former, as it possesses not only all its properties, with a greater uniformity of texture and distribution of magnetic force, but has also the advantage of being moulded into any required shape. The two forms usually given to artificial magnets are shown in Figs. 26 and 27. Fig. 26 exhibits a pair of bar magnets, while Fig. 27 is commonly called the horseshoe magnet.

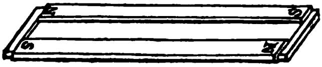
Fig. 26.

42. When a magnetized bar is immersed in iron filings, or if placed upon a sheet of paper, and the filings sifted over, there will be found a greater accumulation of the attracted particles at the ends or poles of the magnet than

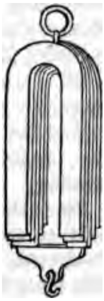

Fig. 27.

any other of its parts, showing that the maximum power of the magnet is at those points.

43. A fundamental principle of all magnetized bodies may be shown by freely suspending on its centre of gravity an artificial bar magnet, or a large sewing needle magnetized, which will then assume a direction nearly north and south. The bar may be drawn from this position, but when again left to itself will, after a few oscillations, invariably present the same end to the north. It is therefore usual to mark that extremity N. which points towards the terrestrial north, and S. that which is towards the south. It must, however, be remembered that the earth or globe plays the part of an enormous natural magnet, having its northern and southern polarity, which is the cause of the directive power of the suspended bar; for as in electricity, so in magnetism, opposite poles attract each other, while similar poles repel: hence that which is commonly called the north pole of a magnet is virtually its south polar point; and the same reasoning applies to the other pole pointing south, which is its north pole, from being attracted by the south pole of the earth.*

44. The polar direction of a freely-suspended magnetic bar or needle varies not only from one place to another, but is subject to certain yearly changes from the true terrestrial meridian in which the observation may be made; hence the plane that passes through the centre of the globe, coinciding with the direction of the bar or needle, is called the magnetic meridian, and the difference between this plane and the true meridian is termed the variation or declination of the needle. This variation was first noticed, with any degree of correctness, in 1581, when it formed an angle with the true meridian of 11° 15′ to the east; in the succeeding century it had diminished to 4° 5′ east; and in 1657 the two planes were coincident in London. In 1665, the needle had assumed a direction of about 1° 30′ to the west, and which went on

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* These terrestrial magnetic poles are by Gauss supposed to be, one, lat. 73° 35′ north, long. 95° west, and the other, lat. 72° 30′ south, long. 152° east.

increasing up to 1818, when it was 24° 41′, its extreme westerly point; since then it has been decreasing, and was in 1850, 22° 30′ west of north.

45. In addition to the above progressive motion of the magnetic needle, Graham, in 1722, observed that the north end of the needle assumed a westerly direction early in the day, and returned eastward to the same position in the evening.

Since that time, Sir W. S. Harris observes,* "that the north pole of the needle begins between 7 and 8 A.M. to move westward, and this movement continues until 1 P.M. About this time the needle becomes stationary, and soon begins to retrograde east, but with a slower motion than that of its previous advance. About 10 P.M. the needle is again stationary at the point from whence it started. A second and smaller oscillation ensues during the night: the north pole moves slowly west until 3 A.M., and then returns again as before.

"The action of the sun is supposed to be the cause of this daily disturbance of the magnetic needle."

46. The directive property of a magnetic needle is of vital importance to the mariner: it furnishes him with an instrument called a compass, by the aid of which he is enabled to determine the several quarters of the horizon. It is also extremely useful in many operations on land, particular to the miner, the surveyor, and the traveller.

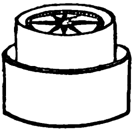
Fig. 28.

47. The Common Compass (Fig. 28) consists of a circular metal box, the bottom of which represents the horizon; from the centre of the bottom projects a steel point, upon which is suspended the magnetic needle; surrounding the needle is a plate, divided at its outer edge into three hundred and sixty equal parts, or degrees; the several points of the compass are also marked upon it; the top of the box has a glass cover to protect the needle from the action of currents of air. In the mariner's compass (Fig. 29) the divided circular plate is a stiff card, affixed to the upper part of the needle, with the north and south points made to correspond with the axis of the needle, and the whole balanced on the steel point; the

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* *Treatise on Magnetism,* part ii. page 86.

compass-box is hung on gimbals, with its centre of gravity much below the points of suspension, to obviate the effect the rolling motion of the vessel would have upon the needle. In compasses thus constructed, the needle moves horizontally: to accomplish this, the needle is balanced after the magnetic property has been communicated to it; for were the needle to be balanced prior to its being magnetized, it would be found to have lost its balance after this had been effected, the northern half of the needle appearing to be the heaviest, dipping down below the horizon. This peculiar effect, viz., the angle thus formed, is called the dip of the needle.

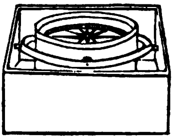
Fig. 29.

48. The amount of this inclination depends upon the latitude of the place where the experiment is made. The discoverer of this phenomenon was Robert Norman, an Englishman, in 1576, who constructed an instrument (Fig. 30) to ascertain the precise angle the magnetic needle would by its dip form with the horizon, which was found to be 71° 51′. The following table exhibits the inclination of the magnetic needle as determined at a few remarkable places of the globe, within a comparatively recent date:—

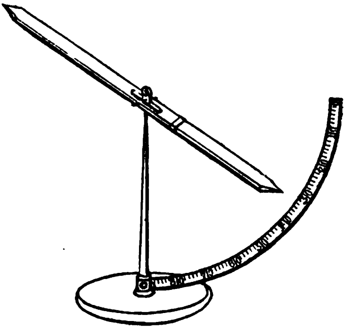
Fig. 30.

NORTHERN HEMISPHERE.

Place.	Rome.	Paris.	London.	Petersburgh.	Honduras Bay.
Dip.	60°	67°	69°	71°	89° 57′

49. The nature of the dip may be familiarly demonstrated by delicately balancing a steel needle, and afterwards mag-

netizing it: the north pole, as before observed, will be depressed. If the needle so supported be passed over a bar magnet, the needle, when brought over either end of the bar, will arrange itself in a vertical position. As the needle is made to pass towards the centre, the angle of the dip will gradually lessen; and when it arrives at the equator of the magnet, the needle will be in the horizontal position, as shown in the following diagram:—

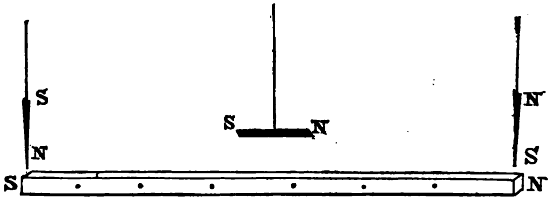

Fig. 31.

50. Although hardened steel is universally employed in the construction of artificial or permanent magnets, yet iron may have communicated to it a temporary state of magnetism by position or otherwise: thus, if a rod of iron—say a poker, for instance—be maintained at an angle of about 69°, and its lower end be applied to the north end of the needle, the latter is immediately repelled; on the contrary, if the poker be lowered (still retaining the same inclination), and its upper extremity be approached towards the same pole of the needle, instead of being repelled, as in the first instance, it will be attracted. Hence we observe that the poker acquires magnetic polarity merely by being placed in the line of the dip, and that the magnetism which exists only while it was at that angle, was induced by terrestrial magnetic action.

51. Magnetic Induction.—If a bar magnet be placed in an horizontal position, and a piece of iron about one-third its length be placed in contact with either pole, so that a portion of the iron shall project over the table, it will be found by examination that the magnetic force exerts its influence through the iron, as shown by the attraction which exists on bringing it in contact with a piece of iron or a small key, which will remain suspended as if in direct contact with the magnet. If, instead of bringing the piece of iron in direct contact with the magnet, it is placed so as to be very near

without its touching it, a similar induced state will be observed: the iron for the time (*i. e.*, while under the influence of the magnet*) is itself a magnet, having a northern and southern polarity, the end next the magnet having a polarity opposite to that of the pole to which it is presented.

52. The natural magnet is seldom resorted to in the present day as an agent for the communication of this force to bars, the artificial magnet being usually employed, offering greater facilities in the manipulation and relative production of magnetic power.

To describe the various modes of magnetizing steel bars, &c., would occupy much time and space, and if carried out, would hardly be attended with any practical result. We shall content ourselves with describing the modes commonly employed, and which by practice are found to answer every requirement.

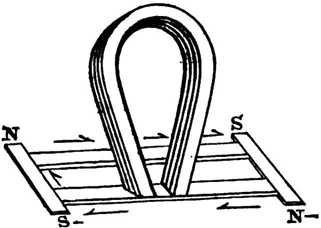

Fig. 32.

53. N. S. N′ S′ (Fig. 32) are two hardened steel bars attached temporarily to any support, to the ends of which SS′ and NN′, two pieces of soft iron of the same thickness and breadth, are secured, so that both pieces shall be in good contact with the bars to be magnetized. This being done, bring a horseshoe magnet into contact with the bar N′ S′, as shown in the figure, taking care that the marked or north pole of the magnet shall be next to the south of the bar N′ S′; now slide the horseshoe magnet over the arrangement of bars several times, taking care not to disturb the contact of the bars or magnet, and to finish the magnetization at the point of commencement: on the process being repeated on each surface of the bars, they will be found to be strongly magnetized. In communicating magnetism to a horseshoe bar of steel, the same arrangement is necessary. In this case, the place at which the inducing magnet should be withdrawn is the point 0 in Fig. 33.

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* Soft iron, for some cause not understood, although capable of receiving magnetism, will not, like steel, retain it after the inducing cause has been removed.

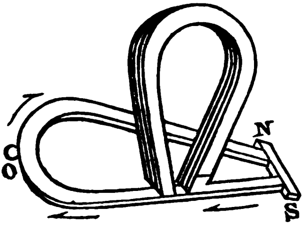

Fig. 33.

54. In the latter end of the year 1824, the attention of the scientific world was directed to the consideration of the effects of different metals on the oscillations of a magnetized needle, by a communication made by M. Arago to the French Academy of Sciences. He observed that the metal rings with which magnetic needles are usually surrounded, exerted a sensible influence on their oscillations, the effect of which was to diminish the amplitude of the oscillations. In this communication he states that a horizontal needle suspended in a ring of wood by a thread with torsion, being moved 45° from its natural position and left to itself, made 145° oscillations before the amplitude was reduced to 10°. In a ring of copper the amplitude so rapidly decreased, that the same needle, on being removed 45° from its natural position, only oscillated thirty-three times before the arc was reduced to 10°. The time of the oscillations appeared to be the same in both rings.

55. The capacity of various metals for the development of this effect may be investigated by putting into rapid rotation metallic discs or plates in approximation with a magnet, and by vibrating metallic discs or plates between the poles of a horseshoe magnet.

56. Babbage's Apparatus (Fig. 34) consists of a compound horseshoe magnet, mounted in such a manner as to permit of its receiving a rapid rotatory motion. A circular disc of copper, or any other metal that may be the subject of the experiment, is suspended centrally without torsion over the magnet; a disc of glass or sheet of cardboard is placed between the two, to cut off any currents of air; as soon as the magnet is made to rotate, the copper will

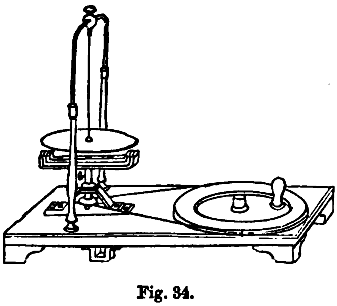

Fig. 34.

commence revolving in the same direction, at first slowly, but with a velocity gradually and steadily accelerating.

57. The experiment may be varied by suspending horizontally a magnetic needle, or straight bar magnet, and putting into rapid rotation a metallic disc underneath it (Fig. 35). The needle or magnet will deviate from its natural position, and finally assume a rotatory motion, corresponding in direction with that of the disc.

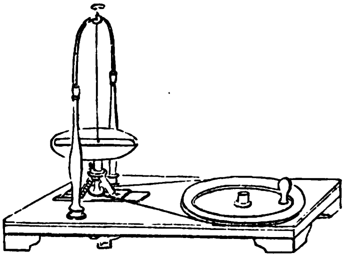
Fig. 35.

58. Fig. 36 is an apparatus invented by the late Mr. Sturgeon, and called by him a "magnetometer." It consists of a circular disc of copper or other metal, with an axis in its centre, formed so as to play freely when laid on the brass supports. A small weight being attached to the lower edge, the discs are easily made to vibrate by reversing the position of the plates. The apparatus illustrates the difference between the number of oscillations made when the vibrations are between the poles of a horseshoe magnet, and when the magnet is not present.

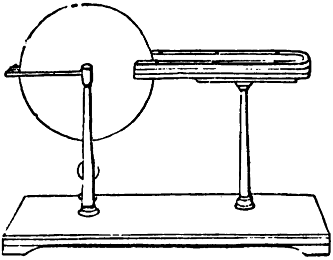
Fig. 36.

59. The above experiments are due to the action of what is now called magneto-electricity, or magneto-electric induction, a phenomenon first satisfactorily explained by Dr. Faraday, which subject will be adverted to in another section.

60. In connexion with our present subject, viz., magnetism, we may here briefly allude to another interesting class of phenomena, discovered by the same eminent philosopher, which he has termed Diamagnetism, and is a term applied by him to all those bodies which, when submitted to

the influence of magnetism, arrange themselves in a line between, but at right angles to, the magnetic poles. The latter direction is denominated the axial, and the former the equatorial position. Thus, if we suppose A B (Fig. 37) to represent the two poles of a powerful electro-magnet,* then the line A B is the axial, while C D would be the equatorial. The various substances submitted to the magnetic influence are delicately suspended between the poles of the magnet.

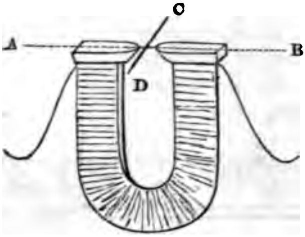

Fig. 37.

61. The following table exhibits the relation of some of the most important metals in this respect:—

AXIAL, *or Paramagnetic.*	EQUATORIAL, *or Diamagnetic.*
Iron	Bismuth
Nickel	Antimony
Cobalt	Zinc
Manganese	Tin
Chromium	Lead
Platinum	Silver
	Gold

62. The action of this force is not, however, confined to the metals; every substance that is not susceptible of the ordinary magnetic polarity (axial) is a diamagnetic body—as phosphorus, wood, apple, potato, flesh, &c.; most of the gases, except oxygen, which ranks as a magnetic body. Our space forbids any further reference to this interesting fact. Dr. Faraday's original papers were published in the *Phil. Mag.* 1846, 1847, and 1851; and others by Professor Tyndall, *Phil. Mag.* 1850, and subsequent numbers.

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* To be hereafter described.

ELECTRO-DYNAMICS.

63. About the close of the last and the beginning of the present century, various attempts were made to establish an identity, or at least an intimate relation, between electricity and magnetism. These experiments were carried out principally by M. Ritter: they attracted, however, but little attention at the time, and no satisfactory results were obtained until M. Oërsted, professor of natural philosophy, and secretary to the Royal Society of Copenhagen, in the autumn of 1819, made his discovery, which, when published, attracted the attention of philosophers in all countries. He found that when a magnetic needle was brought towards a wire through which a current of electricity was flowing, the latter had the power of attracting and repelling it in a constant manner, and in obedience to the following laws:—1st. If the uniting wire joining the two terminals of a voltaic battery is brought horizontally over a magnetic needle while in a state of rest (and consequently in the magnetic meridian), the needle is instantly moved, and eventually takes a position towards the east and west. 2nd. If the wire, instead of being placed above the needle, is brought beneath it, the deflection is in a direction opposite to the former. From these results he deduced the following general law—viz. That end of the needle which is situated next to the negative side of the battery, or toward which the current of positive electricity is flowing, moves to the westward. Again, if the uniting wire, instead of being brought over the needle, be placed in the same horizontal plane with it, and on its east side, the current moving from north to south, the south pole of the needle will be elevated; but if the wire is placed on the western side, then the north pole will be the one elevated; or if the uniting wire is placed at right angles to the needles, and near to one of the poles, that pole will be elevated if the current moves from west to east, and depressed when it moves from east to west. If the uniting wire is placed in such a position as to be in a vertical line, and then brought near to either pole of the needle, the current passing in an upward direction, that pole moves eastward; but if the wire be shifted so as to occupy a position, say midway between the pole and the point of support, the same pole moves westward.

64. Oërsted also ascertained that this action of the current was not intercepted by glass, metals, water, wood, resin, &c., and that the effects obtained were due not so much to the intensity of the current, but almost solely to the quantity circulated. These facts formed the basis of the important branch of physics termed by Oërsted electro-magnetism, under the supposition that it was essential to the development of the effects that a magnetic needle should be one of the elements.

65. The French philosophers soon after discovered that the needle might be dispensed with, and its place occupied by a second conductor. They found that two conductors influenced each other, and exhibited similar effects to the one conductor and a magnetic needle; hence they regarded the result as an effect due to the motion of the electric force in the conductors, and therefore called the phenomena electro-dynamic.

66. In the following brief sketch of this interesting branch of physics, we shall not follow the chronological order of discovery of each fact, but rather endeavour to arrange the whole, so that it is hoped a more general idea may be conveyed than by a series of isolated phenomena.

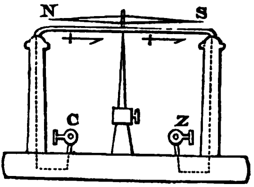

Fig. 38.

67. The leading facts connected with Oërsted's discovery may be very conveniently studied by means of the apparatus (Fig. 38), which consists of a horizontal copper wire, which may be made to form part of the conducting wire carrying a voltaic current. N S is a magnetic needle, mounted on a point and stand, capable of being elevated and depressed, and free to move in a plane parallel with the wire. If the needle be brought above and parallel with the wire and in the magnetic meridian,* and the two wires of a voltaic battery be attached to the apparatus—viz., the wire from the zinc to the screw Z, and that from the copper to the opposite screw C—the direction of the current will be from left to right, or from C Z, and the magnetic needle will

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* This is easily effected by moving the apparatus after the needle has taken its fixed position, so as to bring the wire parallel with the former.

be seen instantly to change its direction, assuming, after a few oscillations, a state of rest nearly at right angles to its former position, the north pole having moved towards the west. Take off the needle, and lower the point so that the needle, when replaced, shall be beneath the wire; it will now be observed that the former is still deflected, but that the north pole has in this position moved eastward. Fig. 39 is another form of exhibiting this experiment, and much more convenient, as the magnetic needle is attached to the wire, having at the same time a free motion in a plane parallel with it, and can therefore be placed in any required position without removing the needle. From these experiments the following facts are proved—viz., that when a wire carrying a current of electricity is placed in the magnetic meridian, and the current moving from north to south in a plane parallel with, but below a magnetic needle, the north pole of that needle moves westward: if, on the contrary, the needle be below the wire, everything else remaining the same, the north end of the needle then moves eastward.

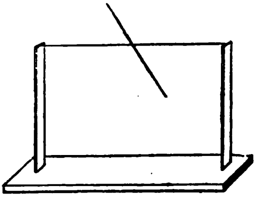

Fig. 39.

68. As the electric current is moving throughout the whole length of the conducting wire, as well as through the battery, it follows that any part of the circuit may be employed in producing these deflections of the magnetic needle; and further, that as the movement of the latter, either to the east or west, depends upon the direction in which the current is moving,* consequently if, as shown in Fig. 40, the conducting wire is doubled by bending back upon itself, and the needle be supported between the rectangle thus formed, the current is moving in opposite direction in the two portions of the wire: in the lower wire it moves from left to right, while in the upper its direction is reversed. By this mode of arrangement

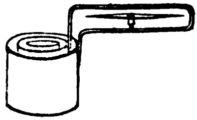

Fig. 40.

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* In all cases, except when otherwise expressed, the current is supposed to be moving in the line of the magnetic meridian.

we are enabled to double the effect of the current upon the needle; for although the wire is both above and below the needle, yet, as the current moves in opposite directions, it produces the same deflecting influence with double the force. The apparatus shown in Fig. 40 consists of a small voltaic battery, which being placed in the magnetic meridian, and a little very dilute sulphuric acid and water, or even common salt and water, poured into the cell, the voltaic action is immediately established. Fig. 41 is another apparatus to show the effects mentioned at 67, and is an instrument well adapted for a class or lecture table illustration. It is formed of a piece of stout brass wire, bent upwards at right angles at each end, and then passed through and secured in a hole made across the upper end of a brass cap, supported upon a wooden pedestal, the two ends terminating in metal cups containing mercury; another wire, secured at one end by any insulating medium to the former, having also a mercury cup; the opposite end of this wire being soldered to the opposite end of the bent wire, as shown in the figure. Upon the brass cap is a conical metal point to support a magnetic needle, which turns upon this point as a centre.

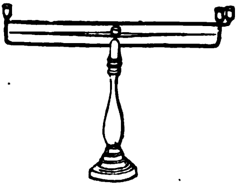

Fig. 41.

Upon making a communication with a voltaic battery, by means of connecting wires, with the two metal cups upon the bent ends of the lower wire, the current passing then below the needle, the latter will be deflected as before (67). If, however, one of the connecting wires be removed to the cup attached to the opposite wire, the current is then transmitted above the needle, the deflection of which will be in a direction contrary to the former.

69. The Galvanometer.—By taking advantage of the above facts, a very valuable and at the same time highly sensitive instrument, under the above name, has been invented, of the utmost importance in the investigation of very many of the phenomena connected with this branch of physics. It consists (Fig. 42) of a

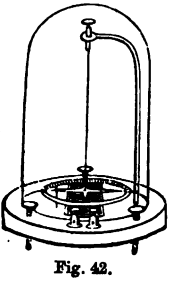

Fig. 42.

rectangular frame of many reduplications* of very fine insulated copper wire. In order to increase the sensitiveness of the needle, it is arranged upon what is commonly called the astatic principle, by which the influence of the earth's magnetism upon it is almost neutralized. This is effected by placing outside and above the coil a second needle, the poles of which are arranged in opposition to the former; thus the attractive influence of the earth on the pole of one needle is to a degree counteracted by its repulsive power on the south pole of the other needle with which it is associated. The needles thus arranged are suspended one within and the other without the insulated coil of wire by a fibre of unspun silk, having the necessary adjustments to allow perfect freedom of motion. In all cases where the deflection of the needles is confined to angles not exceeding 15° or 20°, the amount of deviation may be regarded as giving pretty accurately the relative force; but it is evident that as these deviations increase, *i. e.* the more the needles deviate from their parallelism with the coil, the less powerful will be the deflecting force: hence the amount of power necessary to move the needles over 5° is not the same at every part of the quadrant. Thus, supposing that up to 20° the force required to move the needles over 5° be any given quantity, for the next 5°, viz. an arc of 25°, the force exerted would not be equal to that which caused the deviation from 5° to 10°, but considerably more.† But as this is definite for each case, the force, when necessary, can be easily estimated.

70. These instruments are now made with so much deli-

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* These reduplications are necessary in order to increase the effects of the currents on the needle; for as all parts of the circuit act equally on the needle, the greater the number of these parts brought to bear upon a given point, the greater necessarily is the effect produced.

† The causes operating to produce this effect are, 1st, the magnetism of the earth tending to bring back the needles to the magnetic meridian; 2nd, that as the deflection destroys the parallelism of the coil and needles, the position of maximum power is diminished as the want of the parallelism is increased. This for a small arc is almost insensible, but becomes very considerable as the deflections augment. To obviate this defect, Mr. Peltier substitutes for the astatic needles two others, placed at right angles to each other in the same plane. Thence, what one set loses by the deflection is gained by the other being brought within the influence of the coil.

cacy, and are so sensitive, that the most feeble currents are readily detected by them. At the Great Exhibition, Messrs. Watkin and Hill had one of these instruments with a coil of 690 feet of wire $\frac{1}{150}$ of an inch in diameter. M. Dubois Reymond, the author of some highly valuable researches on the development of currents of electricity in living bodies, has one galvanometer the coil of which is composed of 3280 feet of insulated wire, ·0067 of an inch in diameter, wound over the frame 4650 times, and another with a wire measuring 16,752 feet, making 24,160 times upon the frame. When more powerful currents are the subject of experiment, the

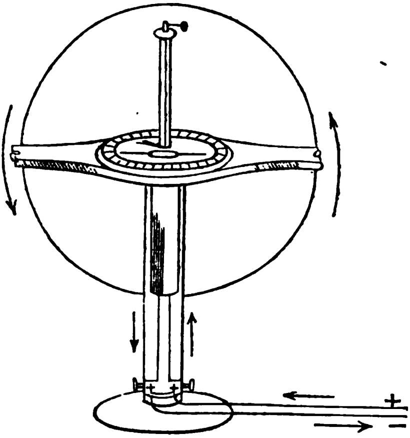

Fig. 43.

71. Tangent Galvanometer is commonly employed. It consists of a graduated circle mounted upon a stand, as shown in Fig. 43, in the centre of which a short magnetic needle is suspended by a single fibre of silk; the two ends of the needle are elongated so as to reach the circumference of the circle by the attachment of two thin wire stems: the conductor through which the current is transmitted is a circle of stout copper wire about a foot in diameter, and mounted as shown in the cut. The instrument, when in use, is placed in the magnetic meridian, the needle being then in a position

parallel to the diameter of the wire. The indications given by this form of the galvanometer are regarded as being tolerably accurate up to about 70°, the force of the current being in proportion to the tangent of the angle of deflection.

72. Differential Galvanometer—Is an instrument designed to compare the relative force of two currents. It is formed of two perfectly similar wires, wound round the same coil, and is mounted similar to that shown in Fig. 42; but as two wires are employed, there will be four ends, which are soldered to four binding screws, forming two distinct circuits. If two opposite currents of equal force are transmitted through the respective coils, no effect on the needle is rendered manifest, for the obvious reason, that as the two currents are moving in opposite directions, they neutralize each other's effects. Should, however, one current be more powerful than the other, a deflection occurs, the amount of which by approximation determines the difference of the two currents.

73. Torsion Galvanometer.—In this instrument, invented by the late Dr. Ritchie, the needles are suspended by a fine thread of glass, which by the deflection becomes twisted: the number of degrees over which the index is moved to destroy the torsion being recorded, the current is withdrawn, and another being transmitted as before, the difference in the number of degrees will give the amount of electro-magnetic force, which is directly proportionate to the number of degrees through which the thread has been twisted.

74. An interesting illustration of the identity of thermo and voltaic electricity in their electro-dynamic effects is obtained by the apparatus Fig. 44, which represents a compound rectangular frame, one half being formed of bismuth, and the other of antimony, united at opposite corners. This frame is erected in a vertical position upon the upper end of a pedestal; it has a hole made in it, through which passes a screwed wire, having a binding nut upon it, by which the frame is firmly secured to the pedestal. The upper end of this wire terminates in a fine point, upon

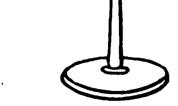

Fig. 44.

which turns a magnetic needle. If the frame be placed in the magnetic meridian, and the needle at rest in its natural position within it, upon applying a spirit lamp to the lower end of the frame, where the two metals join each other, a thermo-electric current is established, and rendered manifest by the deflection of the magnetic needle. Similar phenomena are also exhibited by abstracting heat from one part of the frame, instead of communicating it. If, for instance, one of the compounded corners be enveloped in an absorbent substance, such as filtering paper, and this paper be moistened with any rapidly-evaporating fluid, as ether, &c., the cold thereby produced, or the diminished temperature of that corner of the frame, is sufficient to excite thermo-electricity, which will cause the needle to be deflected in an opposite direction to that in which it is deflected when heat is applied. The maximum effects are produced when the extremities of the elements are in extreme states as regards temperature: it is therefore advisable to abstract heat from one corner of the rectangle, at the same time that it is added to the opposite corner. In this and in all other apparatus where so feeble a current as that produced by a mere difference of temperature in the extremities of any body composed of a metal or metals is to be made manifest, it becomes necessary to neutralize the effects of terrestrial magnetism upon the needle: to obtain this end, we may either employ the astatic needle, formerly described, or arrange an artificial magnet or magnets in such a manner as to overcome the directive tendency of the needle, which may be known by the needle remaining stationary in any position in which it may be placed.

75. The above experiments naturally lead to the conclusion that a wire, while transmitting a current of electricity, exerts a force similar to that of a magnet, but in a direction at right angles to its own motion. That this view is in accordance with the result of experiment, is proved by introducing a thin wire of copper, employed in conveying a current of electricity into some fine iron filings: if the current passing be sufficient in power, the wire will attract the filings, the latter being arranged around the circumference of the former, and along any length of the wire that may be so immersed; on cutting off the current, the action is instantly destroyed. It is evident that the force moving through the wire acted

for the time being as a magnetic body, each particle of iron being magnetized by induction, the inducing force exhibiting its action at right angles to the direction of the current, and in every part of the circuit through which it travels.

76. In the view thus taken of the effect produced by the current upon the needle, the latter might be supposed to be a mere passive agent. This, however, is far from being the case; for if the magnet is fixed and the wire be free to move, the deflection of the wire follows the same law as the fixed wire and moveable needle already shown. To exhibit this phenomenon, the apparatus Fig. 45 may be employed, which consists of a light rectangular frame of copper wire freely suspended on a vertical support, the two ends of the wire frame passing into two separate circular troughs of mercury, which communicate by wires with the two lower mercury cups into which the battery wires are to be placed: on this being carried out, a current of electricity circulates through the frame; if a bar-magnet be now brought near the sides of the frame, attraction or repulsion is produced, depending upon the pole employed.

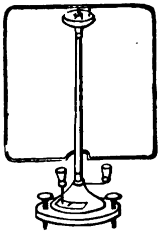
Fig. 45.

77. Another mode of exhibiting this effect is by the Floating Battery, De la Rive, shown in Fig. 46. It is formed of a cylindrical glass vessel, having a cork float attached to its upper end; into this vessel is inserted a small voltaic combination, consisting of a plate of zinc, surrounded by one of copper. An insulated copper wire, affixed by soldering to both plates, is made into the form of a ring, consisting of several coils of the wire; upon pouring dilute acid into the glass vessel, and placing the plates in it, voltaic action commences, and is made evident by placing the apparatus afloat in a basin of water, when the coil will have a tendency to take a position in the plane of the magnetic meridian. The electro-magnetic effect is still more strongly developed on bringing into the vicinity of the coil a powerful bar-magnet. If this be held horizontally in a line coinciding with the axis of the coil, it will be attracted, and continue to

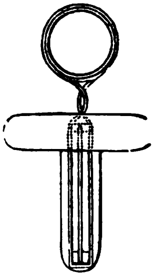
Fig. 46.

advance slowly until the coil or ring envelopes the pole of the magnet, when it proceeds with considerable rapidity to the equator or centre of the magnet, where it remains at rest. If the magnet be withdrawn and its opposite pole be placed within the circle, the ring recedes until it gets off the magnet, where it turns itself half round, presenting its opposite side to the magnet, and instantly approaching it, rushes forward until it has again arrived at its centre, where it remains stationary as before.

78. Fig. 48 represents another arrangement for showing the directive property of a mobile wire when carrying a current of electricity.

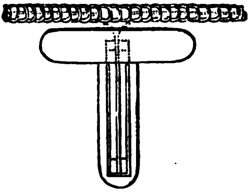

Fig. 48.

The floating glass vessel and voltaic combination are similar to that of Fig. 46; but the insulated copper wire, instead of being coiled into the form of a ring, is made of a helical shape, the two ends being returned through the axis of the helix and brought out near its centre, and then soldered to the zinc and copper plates. Upon pouring the dilute acid into the vessel, and setting it afloat as before, the helix assumes a polar arrangement, its opposite ends indicating different states of magnetism, so as to be attracted or repelled by either pole of a magnet held towards it.

79. Fig. 49 is a third modification of the same experiment. It consists of a wooden stand, upon which is fixed a bent brass standard, having a mercury cup attached. Another cup, containing mercury, communicates by a wire to the little dish of mercury contained in the base of the instrument. The conductor is formed of slender copper wire bent into a flat spiral coil, its upper end terminating in a reversed hook finely pointed, its lower end being brought in a line coinciding with the other termination. On placing the pointed end of the spiral in the upper mercury cup, the lower end

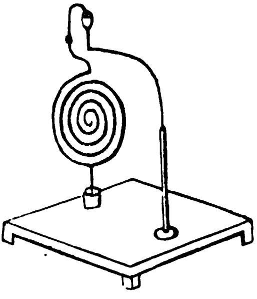

Fig. 49.

dipping into the dish of mercury in the base, it then has a free motion about its vertical axis. Upon the transmission of a current of electricity, the coil will have a tendency to range itself in a plane perpendicular to the magnetic meridian, and, as before, will be attracted or repelled by the pole of a bar-magnet. This apparatus may be modified, and the effects shown in a more positive manner, by substituting for the flat spiral the long helix, shown in Fig. 48.*

80. To account for the foregoing facts, a very ingenious theory has been proposed by the celebrated Ampère; and although it is not our intention, in a work the nature of which is so strictly of an elementary character, to do more than give a popular view of the facts of the science, yet this theory, whether right or wrong, is capable of explaining the existing facts, even to the rigid exactitude required by mathematical analysis.

The theory of Ampère resolves itself into this, that all the effects known and generally recognised as magnetic are due to the action of currents of electricity; or, in other words, that magnetism as a distinct physical force has no existence. To account for the effects commonly called magnetic, he supposes that a current of electricity is continually circulating around each atom or molecule of the magnetized mass, and that the only difference which exists between a magnet and a mass of iron is, that in the magnet these currents are in an active state, while they are latent in the iron. The direction these currents take is supposed to be constant and uniform, and that they circulate in planes at right angles to the axis of the magnetic force.

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* In all cases where wires are employed, perfect metallic contact is essential. It is necessary that all the points of the wires should be cleaned, filed, or rubbed with emery or glass paper, or that they should be amalgamated, so that the current transmitted through the several wires should meet with no interruption. Mercury is frequently used in connecting the points, and is placed in cups on the various electro-magnetic apparatus; and although perfectly clean points to the connecting wire will generally answer the purpose, to obtain the best results they must be amalgamated. The most ready and perhaps the best method to accomplish this, is to rub the parts intended for insertion in the cups with nitrate of mercury. Thus, place a globule of mercury in a glass vessel containing a small quantity of diluted nitric acid: upon dipping the points into the solution, and moving them about in contact with the metal, they will become amalgamated upon the surface.

81. The aggregate effects of such currents may be theoretically represented by a set of resultant currents, or by supposing the force to be that of one current moving in a spiral direction uniformly round the mass.*

82. It must be evident from the peculiar action which we have seen to be exerted by a current of electricity during its transmission through the conductor, it is not only capable of influencing a magnetic needle so as to cause it to move out of the magnetic meridian, but that it is itself a magnet, and should, therefore, be in a position to impart magnetism to ferruginous bodies; and this, we now propose to show, is in perfect accordance with theory.

83. If we draw a steel wire or needle to or fro across the conducting wire from a voltaic battery, during the transmission of the current, the needle will be found to have acquired strong magnetic properties. The above experiment will afford additional interest, if the wire be previously arranged in the magnetic meridian and the current made to pass from south to north: under these conditions, if the needle is drawn across and above the wire, the end of the needle on the east side of it will become the north pole, and that on the opposite side the south pole. Repeat the experiment, but instead of drawing the needle over the wire draw it under it; the poles of the needle will then be the reverse of the former: the same change would, of course, be produced by changing the direction of the current. The annexed figure (50) will by mere inspection show the conditions here established. A B is a portion of the conducting wire, the current being supposed to move from south to north, or from A to B; N S and N′ S′, the needles, the letters indicating their polarities.

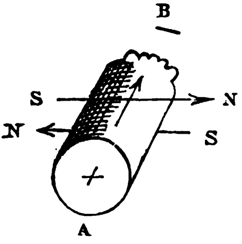

Fig. 50.

84. We have shown (Fig. 67) that when the conducting wire is brought below as well as above the needle, the deflecting force is greatly increased; the same reasoning

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* On this subject the reader may be referred to De la Rive's *Treatise*, vol. i. page 232.

applies to the case of induced magnets by the electric current: hence if the conducting wire be coiled up into a ring or a spiral (Fig. 51) surrounding a glass or paper tube, the united effects of a long length of wire may be concentrated, so as to produce a much more powerful result upon the iron or steel to be magnetized. The apparatus shown in Fig. 51 is formed by winding an insulated copper wire round a piece of glass or cardboard tubing six or eight inches long, and half an inch to an inch in diameter: to the ends of the two wires binding screws may be attached, for the convenience of forming connexion with the battery. On this being done, we have only to introduce for an instant a slender piece of steel (as a sewing or knitting needle) within the tube; on its withdrawal, it will be found to be powerfully magnetized: a piece of iron wire being employed instead of the steel, although possessing equal magnetic power in the coil, has its magnetism instantly destroyed when removed from the helix, or when the circuit is broken. By this arrangement, the convolutions of the helix determine the flow of the current above and below the bar in opposite directions, as indicated by the arrows.

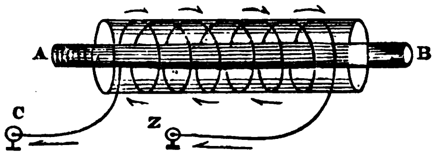

Fig. 51.

85. If the current employed is sufficiently powerful (as from 20 to 40 cells of Grove's battery), and a coil (Fig. 52) of several convolutions is used, on introducing one end of the bar of iron or steel into the hollow axis, a powerful attractive force will be found to be exerted, and the iron, if not too heavy, will rush into the coil, until its centre coincides with that of the surrounding current. If, instead of a bar of iron or steel, a stout darning-needle is presented to the coil, the latter being placed vertically over it, the needle will be seen to rush into the centre, where it remains suspended, in apparent opposition to the laws of gravity.

If a flat hollow coil,* with an opening of three or four inches in diameter, is placed on a sheet of cardboard, iron filings being strewed over the paper within the hollow axis of the coil, the filings, on a current being transmitted through the coil, form themselves into small clusters tending towards the centre of the coil: the same appearance is manifested at the opening, by placing the card and filings upon the upper surface.

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* Flattened copper wire (called copper ribbon) is well adapted for making these coils, when properly insulated.

86. The following interesting experiment is commonly regarded as proving that a molecular movement takes place in a mass of iron or steel at the time of magnetization. Place the coil (Fig. 52) on a firm support, within the axis of which suspend a rod of iron ½ to 1 inch diameter, and not less than 3 feet long—6 to 8 feet gives a better result: if in this state a current of electricity is made to pass through the coil, the bar is instantly magnetized, and at the moment of its magnetization a distinct sound is emitted, sufficiently audible to be heard at the distance of several feet from the bar. "The most brilliant sound is that which is obtained by stretching upon a sounding-board well-annealed wires, one or two twentieths of an inch in diameter, and a yard or two in length. They may be placed in the axis of one or several bobbins, the wires of which are traversed by electric currents, and are thus made to produce an assemblage of sounds, the effect of which is surprising, and which greatly resembles that to which several church-bells give rise when vibrating harmonically in the distance. In order to obtain this effect, it is necessary that the succession of the currents be not too rapid, and that the wires be not too highly strained."* These sounds, given out by iron and by magnetic bodies, seem to indicate, in an evident manner, that magnetism produced by the influence of an exterior current, as well as direct transmission, determines in them a modification in the arrangement of their particles—that is to say, in their molecular constitution. This modification ceases and is instantly produced again by the effect of discontinuity of the current.

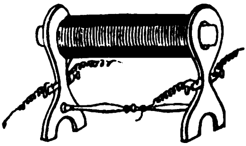

Fig. 52.

87. The polar direction which the steel receives—or, in other words, which end of the bar becomes north, and which

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* De la Rive's *Treatise on Electricity*, vol. i. page 304.

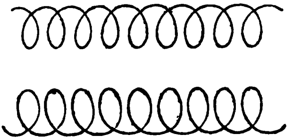

Fig. 53.

south—depends not only upon the mere fact which end of the wire the current enters and makes its exit, but also upon the direction that may be given to the convolutions of the helix. By the inspection of the annexed figure (53), it is evident that the turns which these helices take are in opposite directions, that above being commonly called a right-handed, and the lower one a left-handed spiral.

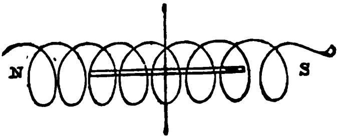

Fig. 54.

88. In Fig. 54 we have an example of a Right-handed Helix, which being placed in the magnetic meridian with the steel bar in its axis, the current being supposed to move from + to —, or from south to north, then N becomes the north pole; but had we taken the left-handed spiral, notwithstanding the current moved from south to north as before, the position of the poles would have been reversed; because of the difference in the position of the convolutions, the current, in its action upon the needle, would be reversed. In a right-handed helix, the south pole is always at the end of the coil at which the + current enters, while it is at the north in a left-handed one.

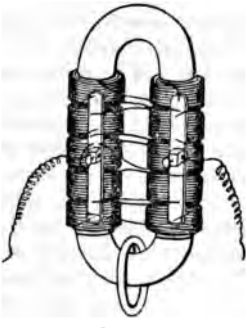

Fig. 55.

89. We have before noticed that soft iron (that is, iron free from carbon) may be rendered magnetic either by induction from a permanent magnet (50), or by the electric current (83). By the latter mode, electro, or, as they are called, temporary magnets, have been constructed upon the horseshoe principle, capable of sustaining several tons weight.

90. Fig. 55 represents a small Horseshoe Electro-magnet, consisting of a cylinder of soft iron,

about one inch in diameter, surrounded by distinct coils of insulated copper wire; the commencement and terminations of the several coils of wire are soldered to two binding screws attached to the legs of the magnet; when a current of electricity from 4 of Grove's battery having four square inches of surface is employed, it will sustain many hundred pounds weight. Dr. Lardner* describes an electromagnet of extraordinary power, constructed for the Faculty of Sciences at Paris, under the direction of M. Paulet. It consists of two horseshoes, the legs of which are presented to each other, the bends being turned in contrary directions. The superior horseshoe is fixed in a frame, the inferior being attached to a cross piece, which slides in vertical grooves formed in the sides of the frame. To this cross piece a scalepan is suspended, in which weights are placed. Each of the horseshoes is wrapped with 10,000 feet of covered copper wire, and they are so arranged that the poles of contrary names shall be in contact. With a current of moderate intensity, the apparatus is capable of supporting a weight of several tons.

91. The Earth's Magnetism.—This important subject, which has given rise to so many theories and vague speculations both in times past and present, has received, since the discovery of the facts connected with thermo-electricity and electro-magnetism, a solution which, although we are not in a position to pronounce with dogmatic assertion, is the absolute cause of the effect, yet there is no other theory which can be said to bear comparison with that which assigns the earth's magnetism to the effect of electric currents, or rather thermo-electric, circulating in a direction east and west, and producing thereby the development of magnetic force at right angles to their own path, or in a direction coinciding nearly with the terrestrial axis. These thermo-currents are supposed to be generated during the diurnal rotation, by which the equatorial regions, conjointly with those of the poles, establish all the conditions required; the earth, in fact, being an enormous thermo-battery, the sun on the one hand and the polar cold on the other furnishing the heat and cold necessary for its due action. Whether this be true, or only at the best a very plausible theory, our present knowledge of

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* *Handbook*, second course, page 335.

the facts will not enable us to determine; but we are in a condition to prove (granting the existence of these currents) that such effects as we know and observe by the term magnetic would be the necessary result, and may be illustrated by an apparatus called "Barlow's Electro-magnetic Globe" (Fig. 56), which is a hollow globe of wood or paper, coiled around the equator of which, and extending above and below, is an insulated copper wire, the two ends of the wire being soldered to the metallic axis with which globes are usually provided.* These spindles serve to support the globe in its frame, and also for the entry and exit of the electric current in its passage through the coil. On applying the wires of the battery to the binding screws attached to the base, the globe instantly assumes the condition of a magnet, its poles being at right angles to the motion of the current passing through the coil. This fact is proved by bringing a magnetic dipping-needle over various parts of its surface.

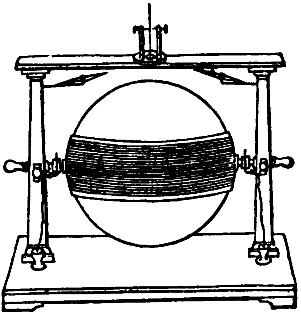

Fig. 56.

92. The extraordinary power exerted by electro-magnets, and the facility with which that power may be destroyed on the current ceasing to pass, has given rise to many attempts to apply this force as a motive power.† This subject has been very ably discussed by Liebig in his "Familiar Letters," page 153. He starts with the well-known truism, "Out of nothing, no kind of force can arise." "We know that in

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* The situation of the globe is altered, the poles being brought into the equatorial position.

† Professor Jacobi is reported to have succeeded, in the year 1839, in propelling on the Neva, by means of electro-magnetism, a small vessel 28 feet long and 7½ wide, containing ten persons, at the rate of four miles per hour. The battery he employed consisted of sixty-four pairs of grooves, each platinum plate having a surface 36 inches square. Mr. R. Davidson, in 1842, is also said to have constructed an electro-magnetic machine weighing four tons, which was propelled on the Edinburgh and Glasgow Railway at the rate of four miles an hour.

this case the moving force is produced by the oxidization of the zinc; and setting aside the name given to the force in this case, we know that its effects can be produced in another manner. If we were to burn the zinc under the boiler of a steam-engine, consequently in the oxygen of the air instead of the voltaic battery we should produce steam, and by it a certain amount of force. If we should assume (which, however, is not proved) that the quantity of force is unequal in these cases—that, for instance, we had obtained double or treble the amount in the battery, or that in the mode of generating force less loss is sustained—we must still recollect that zinc can be represented by an equivalent of carbon (or coal). According to the experiments of Despretz, six pounds weight of zinc, in combining with oxygen, developes no more heat than one pound of coal; consequently, under equal conditions, we can produce six times the amount of force with a pound of coal as with a pound of zinc. It is, therefore, obvious that it would be more advantageous to employ coal instead of zinc, even if the latter produced four times as much force in a voltaic battery as an equal weight of coal under a boiler. . . . . Heat, electricity, and magnetism are equivalent to each other, and to the electricity producing them, just as carbon, zinc, and oxygen are. By a certain measure of electricity we produce a corresponding proportion of heat, or of magnetic power, equivalent to each other, and to the electricity producing them; we purchase that electricity with chemical affinity, which in one shape produces heat, in another electricity and magnetism. A certain amount of affinity produces an equivalent of electricity, in the same manner as, on the other hand, we decompose equivalents of chemical compounds by a definite measure of electricity. The cost of the magnetic force is, therefore, in this case, the cost of the chemical affinity."

"It is true that, with a very small expenditure of zinc, we can make an iron bar a magnet capable of sustaining a thousand pounds weight. Let us not allow ourselves to be misled by this: such a magnet could not raise a single pound weight of iron two inches, and therefore could not impart motion. The magnet acts like a rock, which, while at rest, presses with a weight of a thousand pounds upon its support: it is like an enclosed lake without an outlet and without a fall. It remains certain that, with the exception perhaps of the boiler, nothing in our machines will be altered on this account; and that, even with our present form of boiler, one pound of coal under the boiler of a steam-engine will give motion to a mass several hundred times greater than a pound of zinc in the battery."

93. Dr. Botto, of Turin, from his experiments on this subject, considers that forty-five pounds of zinc, used in a Grove's battery, would be the quantity necessary to work a one-horse power electro-magnetic machine for twenty-four hours. This at 3d. per lb., = 11s. 3d.; to which must be added 50lbs. nitric acid, at 6d., = 1*l.* 5s.;—this gives 1*l.* 16s. 3d. cost, for twenty-four hours. In this estimate, the sulphuric acid and the mercury are supposed to equal the value of the sulphate of zinc produced during the action of the battery.

94. Electro-magnetic Rotation.—The fact of our being enabled to change the polarity of an electro-magnet by altering the direction of the current, or instantly to destroy the magnetism by cutting off the supply of electricity, has led to the construction of several ingenious instruments under the name of electro-magnetic machines. One of the most familiar is that invented by the late Dr. Ritchie (Fig. 57). It consists of a permanent horseshoe magnet, fixed in a vertical position to a foot of wood or brass, the poles of the magnet being placed upwards: upon a central stem is a cup of wood, divided into two compartments, filled with mercury, into which the battery wires are made to pass, working upon a spindle; within this cup is the small rotatory electro-magnet, the two ends of its coil being so arranged as to terminate one in each of the divisions containing the mercury in the cup. On connecting the wires of the battery with these divisions, the bar of iron, if placed so that its wire touch the mercury, becomes an electro-magnet, and being free to move, immediately obeys the laws of attraction and repulsion mutually exerted between itself and the permanent horseshoe magnet. The motion to which this gives rise, causes the electro-magnet to move through half a revolution, by which the direction of the current is changed and the polarity reversed: this being repeated at every half revolution, produces a continuous rotatory motion, which, if the

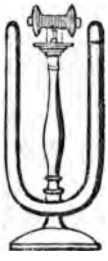

Fig. 57.

battery is at all powerful, is so rapid as to cause a vibrating movement in the whole apparatus.

95. Electro-magnetic Mill.—In this we have an example of the permanent magnet being the rotating body. To the base of the apparatus (Fig. 58) is attached two electro-magnets, their curved position being hid beneath the stand; on the top of the central stem is a wooden cup, divided into four compartments, into which the wires from the electro-magnets pass: the vanes are each formed by uniting on the square spindle two bent permanent magnets; on the middle of this spindle wires are so arranged as to dip into their respective cups of mercury alternately, two and two, by which the polarities of the electro-magnets are reversed and the rotation maintained.

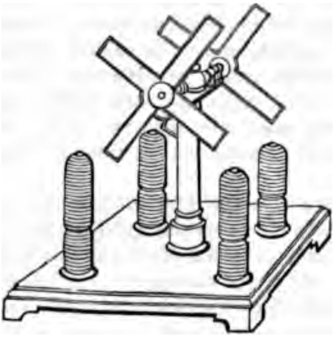

Fig. 58.

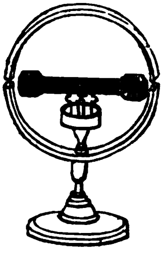

Fig. 59.

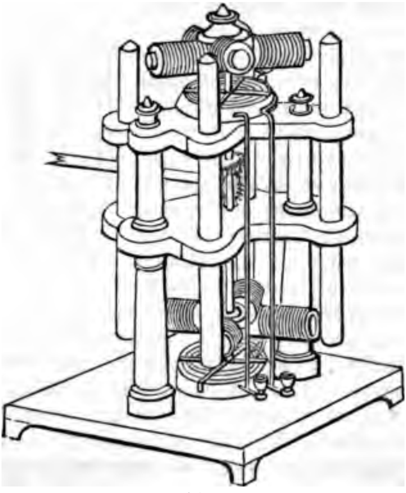

Fig. 60.

96. Fig. 59 is a modification of Ritchie's Apparatus (Fig. 57), the only difference

being in the arrangement of the permanent magnets, which in some cases are mounted upon centres, the effect of which is a double rotation in opposite directions of the permanent and electro-magnets.

97. Fig. 60 is an Electro-magnetic Machine on a large scale, which, when actuated by two of Grove's batteries of four square inches each, is capable of giving motion to small working models of machinery, &c. It has four vertical permanent magnets, and four horizontal electro-magnets; the mercury connexion in this arrangement is dispensed with, and its place supplied by a disc of brass, into which slips of ivory are introduced, the currents being conveyed by springs slightly pressing on the peripheries of the discs.

98. In the arrangement shown in Fig. 61, we have a Compound Horizontal Magnet, the revolving electro-magnets being placed in front of the poles of the former. The contact breaker being attached to the revolving magnet, is so arranged that the motive power is due to the sum of the attractions, and not the difference, as in many other combinations.

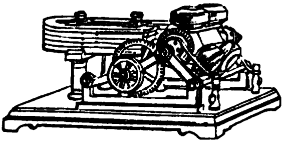

Fig. 61.

99. Electro-magnetic Pendulum (Fig. 62).—To the base board is fixed a metal stem, from which is suspended a rod of wood; to this is fixed (to serve as the pendulum bob) a circular mass of soft iron; at either end of the board is fixed an electro-magnet; in the front of and between the poles of each is a slip of brass, projecting about half an inch beyond the magnet; by bringing up the pendulum against one of the electro-magnets, the strip of brass is thrown back, by which the current of electricity is made to traverse the coil of the opposite magnet. The pendulum being released, the momentum which it has acquired receives an additional impulse in its upward arc by the attractive force of the electro-magnet

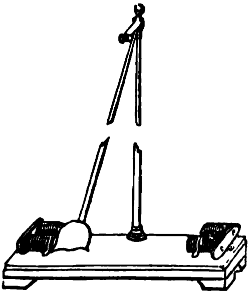

Fig. 62.

towards which it is approaching; this is sufficient to cause it to strike back a corresponding slip of brass, thus turning the current on to the magnet it has just left, by which alternate action the motion of the pendulum is preserved during the action of the battery.

100. Electric Telegraph.—Our limited space will not allow of our noticing the numerous inventions which have from time to time been brought before the public under this head: the only instrument for which we can find space is that to be seen at nearly all our railway stations, commonly known as Cook and Wheatstone's needle telegraph. As the general principle is the same whatever may be the means employed in giving the indication, or the nature of the source from which the electric power is obtained, it is less necessary to notice every invention.

101. In every telegraph system upon this system, there must be—1st, its source of electric power; 2nd, the means of conducting that power to its destination; 3rd, the arrangement to render visible the movements of the currents; and lastly, some conventional system by which these movements shall be understood and recognised as referring either to words, letters, or figures.

102. 1st. The Source of Electric Power.—In almost every system, both at home and abroad, the voltaic battery is made use of as the electro-motive force. In one or two cases magneto-electricity is employed; but, generally, (at least in this country,) it is the old form of battery, consisting simply of zinc and copper plates, placed in wood, earthenware, or gutta-percha cells, filled with fine sand, the zinc plates being amalgamated,* and the whole brought into action by moistening the sand with dilute sulphuric acid. Batteries thus arranged will keep in action for several months.

103. 2nd. The Means of conducting the Current to its Destination.—In this country (for lines above-ground) galvanized iron wire, about one-sixth of an inch in diameter, is universally employed. The zinc coating which it receives in the process so called galvanizing, prevents that oxidization of the

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* This is effected by dipping the zinc plates into a solution of bichloride of mercury: they thus acquire a surface of mercury which combines with the zinc, and prevents the acid from attacking the plate *when the battery is* not in use.

iron which otherwise would be set up, and the wire quickly destroyed. Copper is a much better conductor of electricity than iron, and is far less influenced by exposure to air and moisture, consequently a much thinner wire could be employed; but the great difference of price between the two metals is a barrier to its general use, more particularly as the inferior conducting power of the iron can be compensated for by employing thicker wire and a little more battery power.

104. The means employed to support this wire is well known, but something more than mere support is required. It is a law in the transmission of electricity, that it invariably moves in the line of least resistance; the line of greatest resistance is obviously the wire from station to station; should any other channel exist, offering less resistance, the current, either in whole or part, will take that direction in preference to the former; to guard against which is a difficult problem in telegraphic engineering. Various devices are and have been employed, both at home and on the Continental lines. It may be asked, is not wood a very bad conductor, when compared with metals? Undoubtedly, perfectly dry wood is a very bad conductor; but the posts on which the wires are supported are seldom if ever in that state. Internally by absorption, and externally by deposition, more or less moisture is constantly present; hence the necessity of insulating the wires from the posts, and of preserving the latter at the points of attachment as free from moisture as possible. Although the metal wire has a conducting power many thousands of times greater than wood (14), yet bad as the conducting power of the wood may be, the total resistance resulting from a very long line of wire may be considerably greater than a very much shorter one of wood; in other words, the electric current, instead of traversing the long line of the telegraph wires, finds less resistance in passing down the moistened surface of the post. To prevent this loss of battery current, the wire, at its point of support, passes through or upon a glass or earthenware insulator; but notwithstanding every effort, a very considerable loss is sustained, more particularly in wet weather.

105. In the transmission of an electric current, it is well to remember that it can only move in what is technically called the circuit; that being any conducting body joining the two plates, if only a single pair, or of the terminal plates if a

compound series is employed: consequently, in arranging a telegraphic wire on a line of railway, it is not merely necessary to carry a wire from the one side of a battery at one station to the indicator at the other, but to complete the circuit by a corresponding or, as it is termed, a return wire, which must be brought back the whole length and into metallic contact with the opposite end of the voltaic arrangement from which it started. At least, such an arrangement was thought to be necessary at the commencement of this great undertaking: since then a different system has been adopted, which truly forms one of the marvels of science, that of using the conducting power of the earth instead of the second wire (called the earth circuit). In order to explain this interesting and important fact, let C, Fig. 63, be the voltaic battery, D, E the one line of wire, D and E being the two stations, and A B the earth's surface; then a current being sent through the line of wire E to the station instrument F, it passes from thence by the wire B to a plate of copper G, buried some feet in the earth; from the plate G it is conveyed by the earth to the plate H, likewise buried in the earth, and from it through the wire to the other end of the battery; thus completing the circuit from G to H (the earth circuit), which circuit answers equally well, whatever the distance may be. In reference to this curious fact Dr. Lardner remarks, in his work on this subject—"Of all the miracles of science, surely this is the most marvellous. An *electric current* has its source in the cellars of the Electric *Telegraph Office*, Lothbury, London; it flows under the

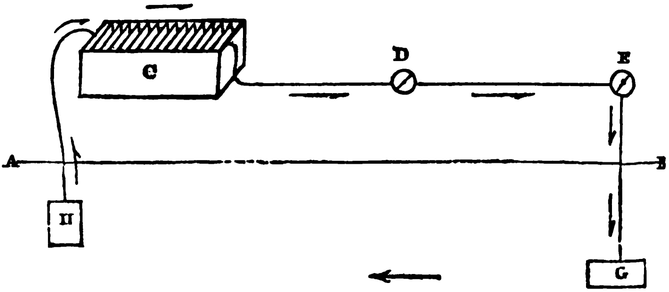

Fig. 63.

reets of the great metropolis, and, passing over wires susended over a zigzag series of railways, reaches Edinburgh, hen it dips into the earth and diffuses itself upon the uried plate. From that it takes flight through the crust the earth, and finds its own way back to the cellars at othbury!"

106. The Arrangement to render visible the Movement of ie Current.—It is hardly necessary to observe that the pasge of the electric current through the wire is, under ordiary circumstances, an effect that is not cognizable to the

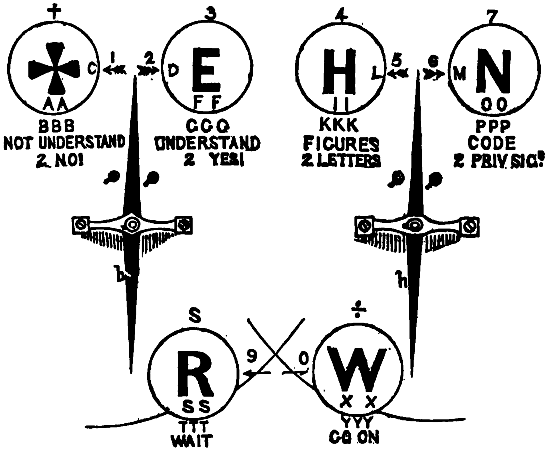

Fig. 64.

enses; its presence, therefore, has to be made known by ome means, and these may be either visual or audible. In he needle telegraph both are adopted; for were they only to nake use of the former, it would render it necessary on the art of the attendant to be constantly watching the instrunent; but by the production of an audible signal, the station lerk, during the interval that the telegraph is not in operaion, may be engaged upon other matter, provided he is vithin sound of the signal.

107. The visible signal is produced by the deflection of the nagnetic needle, and is, in fact, little more than a well-con-

structed galvanometer (42), the coil being in a vertical position, and attached to the back of a dial or front, on the surface of which are placed the letters of the alphabet, and towards which, either to the right or left, the index needle is made to point by the fact of simply reversing the direction of the current through the surrounding coil. The accompanying figure (64) exhibits a view of the dial-plate of the needle telegraph, with its indicating needles: by the movement of two handles attached to the front of the instrument in connexion with what is called the commutator, the operator is enabled to direct the current through one or both coils, and to change its direction as occasion may require.

108. The System of Signals.—As the needle telegraph with one pointer or needle gives but two signals, viz., a deflection to the right or the left, its indications can only be multiplied by increasing the number of coils and line wires, &c.: two coils and needles are, however, quite sufficient for all practical purposes. The alphabet, by the movements of two pointers, is obtained in the following mode:—1st, with the left-hand needle the letters A B C D E F G are obtained, thus:—When the needle is seen to move twice to the left, or points twice to the circle with the cross, that is taken as meaning the letter A; if three times, B; to the left and then right, C; but if it moves to the right first and then to the left, D; once to the right, E; twice to the right, F; three times, G. These movements being repeated in the same order with the right-hand needle, we obtain the letters H I K L M N O P.* In forming the letters R S T U V W X Y and Z, both needles are moved at the same time: thus, if both needles are seen to move once to the left, that signifies R; twice to the left, S; and so on. This system, which to a stranger is perfectly unintelligible, is nevertheless very easily acquired; but the celerity of the operator in transmitting a message, and the quickness of the eye in reading it off at the other station, is a work of time and practice. This telegraph, in its ordinary business, is capable of transmitting from sixteen to twenty-four words per minute.

109. The audible signal is produced by a bell attached to a clock-work movement, which, by means of the attractive

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* The letters J and Q are generally omitted, being unnecessary, as their place can be supplied by others when required.

power of an electro-magnet consequent upon the transmission of the current, gives freedom to the wheel-work by which the bell is struck. The attendant in charge of the telegraph, on hearing this, goes to his instrument and replies to the signal by ringing his correspondent's bell, thus intimating that he is ready to receive the message. The electric current is then in both cases turned from the alarum on to the telegraph, and set to work.

110. Electric Clocks.—This interesting and valuable application of electro-magnetism at one time bid fair to become the universal agent for regulating and maintaining the whole of the clocks in the metropolis, if not throughout England; but either from the want of proper encouragement, or from the difficulty and expense of carrying out the project, it seems, with the exception of the electric clock belonging to the Telegraph Company in the Strand,* to have died away; at least, but little has been heard of it for some time.

The inventors who have most distinguished themselves in this country in perfecting this desirable object are Professor Wheatstone, and Messrs. Baine and Shepherd. The large electric clock of the latter inventor, which occupied so prominent a position in the Great Exhibition of 1851, will be in the recollection of all. A full description of the working of these clocks could not be rendered intelligible without very elaborate diagrams; and even then the subject belongs more to mechanism than electro-magnetism.

111. The Influence of Electric Currents on each other.—About the year 1820, Ampère discovered that similar deflections to those due to the action of the current on the magnetic needle might be produced by two wires conveying currents of electricity. We have already shown (82, 83) that wires transmitting electric currents possess all the properties of common magnets.

112. In order to explain the fundamental principle deduced by Ampère from his discoveries (80), let the circles A B, Fig. 65, represent the diameter of two wires conveying currents of electricity; in A the current is coming through the wire towards the spectator, while in B it is going, we will

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* This clock is worked by the electro-magnet: the battery and apparatus being situated at the Greenwich Observatory, the clock gives Greenwich time.

suppose, from him through the wire: the tangential arrows surrounding the circles show the direction of the magnetic force in each, which, for sake of illustration, may be regarded as so many magnets. It is well known that in magnetism similar

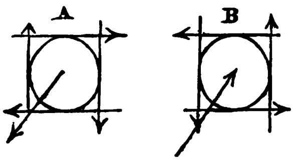

Fig. 65.

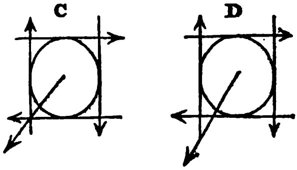

Fig. 66.

poles repel, whilst opposite poles attract, each other: it is evident, then, that when the current moves through the two wires in opposite directions, A B, repulsion must result from the similarity of the polar arrangement; so also when the current moves through two wires in the same direction, C D, Fig. 66, attraction must follow, provided the wires are in a condition to exhibit the effect. This condition of the wire is shown in the annexed figure (67). A is a rectangular wire frame freely suspended on a vertical stand, with a contrivance for passing the electric current through the frame: if a second wire, B, carrying a current in the opposite direction, be made to approach the side of A, repulsion ensues; if, on the contrary, the current in B is in a corresponding direction with A, then attraction takes place. Fig. 68 is an apparatus contrived to show the mutual attraction and repulsion of wires transmitting rectilineal voltaic currents. The two wires are suspended vertically; mutual attraction results when the currents flow in the same *direction,* and repulsion when the current passes in the con*trary; the ends* of the wire dip into their respective mer-

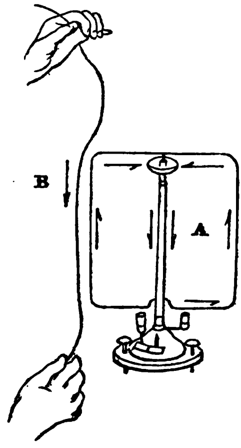

Fig. 67.

cury cups, into which also must be placed the wires from the battery.

113. Electropeter, Reotrope, or Inversor.—It is frequently found necessary in electro-magnetic investigations to change the direction of the current. To avoid the trouble and inconvenience of removing the wires and otherwise disturbing the arrangement of the apparatus, various instruments under the above names have been invented. The following invention by the late Dr. Golding Bird* will be found very convenient for the purpose. It consists of an elevated covered ridge, A B (Fig. 69), composed of three stout pieces of brass, A P B, separated at the dark portion by wood. A and B communicate by means of a thick wire passing under the base of the instrument. Two thick quadrangular bars of brass, D E, pass through a circular piece of wood, F, and terminate in the binding screws G H; the piece F moves on a centre, the bars D E being made to press upon the curved ridge A B by means of a screw at F; the two other binding screws, L M, are connected with A and P: by simply sliding the arms D and E to the right or left over the raised piece A B, the direction of the current is changed without further trouble.

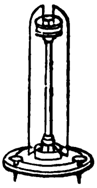

Fig. 68.

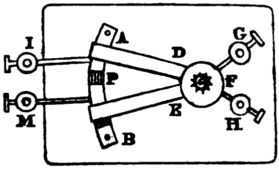

Fig. 69.

114. Electro-magnetic Rotations.—In addition to the movements already described (67, 68) as resulting from the mutual action of the conducting wire and the magnetic needle, Dr. Faraday, in 1821, while carrying out a series of experiments, was led to conclude that the pole of the magnet had a tendency to revolve round the wire, and, consequently, the wire round the pole. An article on this interesting discovery was published by the author in the *Quarterly Journal of Science* for October, 1821, from which the following extract is taken:—"On placing the conducting wire perpendicularly, and bringing a needle towards it so as to ascertain

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* *Natural Philosophy*, vol. iv. page 382.

the attractive and repulsive position with regard to the wire, instead of finding these to be four, one attractive and one repulsive for each pole, thus allowing the needle to take its natural position across the wire, and then drawing the support away from the wire slowly, so as to bring the north pole, for instance, nearer to it, there is attraction, as is to be expected; but on continuing to make the end of the needle come nearer to the wire, repulsion takes place, though the wire still be on the same side of the needle. If the wire be on the other side of the same pole of the needle, it will repel it when opposite to most parts between the centre of motion and the end, but there is a small portion at the end where it attracts it." By referring to Fig. 70, which represents sections of the wire in its different positions to the needle, all this will be plain. The active poles are represented by dots, and the arrow-heads show the tendency of the wire in its positions to go round these poles.

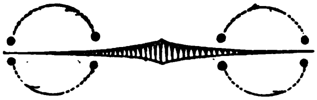
Fig. 70.

115. Dr. Faraday, reasoning on these facts, drew the important inference, that the true pole of the magnet was not at its extremity, but in its axis, a little remote from it towards the centre; and that as there existed no real attraction between the wire and either pole of the magnet, that the wire ought to rotate about the magnetic pole, and the magnetic pole about the wire.

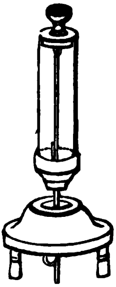
Fig. 71.

116. Fig. 71 represents Faraday's Apparatus to exhibit the revolution of an electrified wire. It consists of a glass cylinder, mounted upon a small rod of iron, affixed to a wooden support, and having a copper wire loop passed through the centre of its cap, and a metal cup to contain mercury above the wire loop. The soft iron rod of the support projects above the bottom of the glass cylinder, and is rounded at its top. Mercury is placed within the lower part of the glass cylinder, and also in another cup, formed in the wooden support. A platinum wire, having a loop formed at its upper end, is loosely hung to the loop on the cap, so that it just touches the surface of the mercury within the glass cylinder.

Upon making a communication with the battery by means of two connecting wires placed in the mercury in the upper and lower cups, and bringing a magnet into contact with the lower part of the iron rod which projects below the wooden support for that purpose, the effect of the electro-magnetic action will be observed by the revolutions of the platinum wire round the induced magnet in the lower part of the apparatus; the direction of rotation depending on the magnetic pole opposed to the wire, and the direction of the electrical current through the wire.

117. The revolution of the wire about the pole, and the magnetic pole about the wire, may be shown by the following apparatus, Fig. 72:—

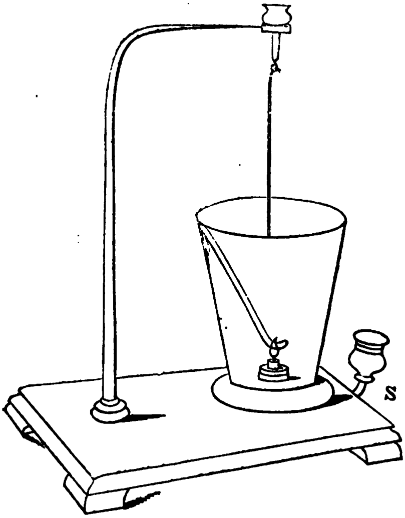

Fig. 72.

On the wooden stand is a bent brass arm, at the upper end of which a vertical screw is passed; to the lower end of this screw a platinum loop is soldered, and a fine platinum wire is hung to that loop; the upper end of the screw terminates in a cup to hold mercury; a glass vessel, having a hole perforated through its base, is placed upon the wooden stand, having a corresponding hole through it; a wire, bent up at each end, is secured underneath the bottom of the stand, the end of which passes through the holes in the stand and in the glass vessel, to which a small magnet is attached, so as to move freely. To the outer turned-up end of the wire a mercury cup is affixed; mercury being then put into the glass vessel, to a sufficient height to reach the lower end of the platinum wire, and a communication being made with the battery, the wires and magnet will then revolve about a common axis in conical surfaces, having their points of suspension as vertices.

118. An interesting modification of the first experiment was invented by the late Mr. F. Watkins (Fig. 73), to show the contrary rotation of two electrified wires, each about its respective axis. Over the horseshoe magnet two helical coils of copper wire are suspended, having slender bars across their tops, with needle points in the centre; these turn in conical holes, drilled in the ends of the magnet; above the points are two small platinum cups, to hold each a globule of mercury; two wooden cisterns are attached by screws on the lower parts of the magnet, carrying mercury cups; to the lower ends of the helical coils are soldered pointed wires, bent so as to enter slightly into the mercury contained in the cells attached to the magnet; a brass standard, fixed to the basis of the apparatus, has a forked piece attached to it, with two points descending into the two platinum cups upon the tops of the coils; and there is also another cup placed on the forked piece, to contain mercury. When the current passes through the apparatus, the helical coils revolve rapidly in contrary directions.

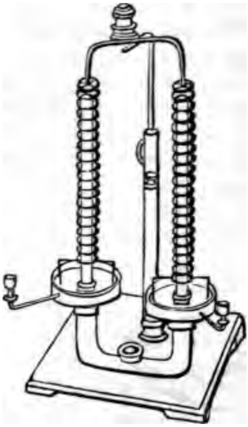
Fig. 73.

119. Instead of two helical wires, the apparatus Fig. 74 *may be employed*, which exhibits the rotation of two metallic

cylinders, the contrivance of Professor Barlow. By unscrewing the cross piece, Fig. 73, the coils may then be removed and the cylinders substituted for them; the circular mercury trough around each limb of the magnet must then be raised, so that the mercury just touches the lower edge of each cylinder; on restoring the cross piece and applying the battery current, the rotation of the cylinders is immediately established, rotating as before in opposite directions.

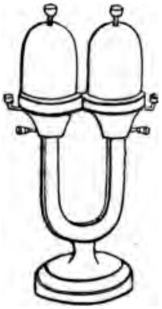

Fig. 74.

120. We stated (115) as a necessary consequence, that if the wire revolves round the pole, the latter should also revolve round the wire. This fact is beautifully illustrated in the following experiment:—

121. The apparatus Fig. 75 is constructed to exhibit the rotation of the contrary poles about two electrified wires. Two flat bar magnets, doubly bent or curved in the middle, each having under the inverted part an agate centre fixed, by which it is supported upon an upright pointed wire fixed to the stand of the apparatus, and upon which it turns round as upon an axis. Above the agate caps, cisterns to hold mercury are also placed. Two circular troughs to contain mercury are supported upon the stage, having holes in their centres to allow the magnet to pass through. A bent pointed wire passes into the cistern of each magnet, the ends of which dip into the mercury contained in the troughs upon the stage; and through the sides in the troughs wires are passed, entering into the mercury, the opposite ends bearing mercury cups. A hollow pillar is firmly fixed to the stage, in which a bent wire supporting another cross wire is inserted, and is capable of being raised or

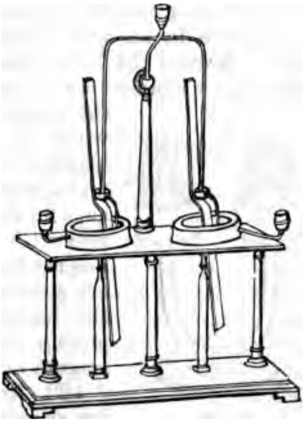

Fig. 75.

lowered at any required height by a binding screw. The two ends of the cross wire are bent downwards and pointed, and made to enter the two small cisterns fixed to the magnets. A third cup containing mercury is provided at the top of the cross wire: on communication being made with the voltaic battery, viz., the wire from the positive extremity being placed in the upper cup, and that from the zinc in each of the lower cups, the magnets will begin to rotate in opposite directions.

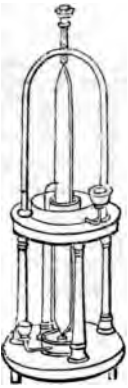
Fig. 76.

122. Ampère, hearing of Dr. Faraday's experiment on the rotation of the wire round the pole of a magnet, was led to infer that a magnet might be made to rotate on its own axis within the electric current, itself being the conductor. The apparatus shown in Fig. 76 is arranged to illustrate this fact. A flat bar magnet is supported in a vertical position by an upright metal wire fixed in the foot of the apparatus, having a hole in the centre containing an agate cup to receive the lower end of the magnet; its upper end turns in another hole made in a vertical screw, with a milled head, which is passed through a screwed hole made in an arched piece of wire fixed to the wooden foot. Around the lower wire is a circular trough containing mercury; a similar trough, having a hole in its centre to allow the magnet to pass through and revolve within it, is placed near the middle of the magnet. These mercury troughs have metal wires passing into them, to support cups for mercury to effect the communication with the voltaic battery. Into the magnet two small bent and pointed wires are screwed, the ends of which dip into the mercury in the troughs. On completing the circuit with the battery, the magnet begins to rotate.

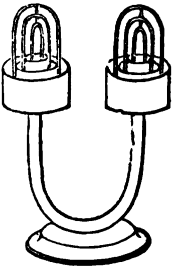
Fig. 77.

123. Ampère devised another apparatus for showing the rotation of the wire round the pole of a magnet, in which the battery itself formed the rotating body. Fig. 77 is a *horseshoe magnet* attached to a metal foot, its poles having

a small hole drilled for the reception of an agate cup. A double cylindrical copper vessel has a bent metal wire affixed to the top of its inner cylinder, through which passes a wire pointed at both ends, the lower point serving as a pivot for its support when placed over the magnet. Two hollow cylinders of zinc, each provided with similar bent wires, having holes made in the under side, are then placed within the double copper vessels; the holes in the bent wires being hung upon the upper points of the wires of the copper cylinders. On dilute sulphuric acid being poured into the space between the two copper cylinders, the voltaic action commences, and presents the phenomena of the whole four cylinders revolving upon their axes, the copper vessels moving in one direction, and the zinc in the opposite.

124. The late Mr. Marsh was the first to exhibit the effect of a pendent wire when exposed to both poles of a magnet. The apparatus Fig. 78 has been already described (Fig. 49). Remove the flat spiral coil from its position, and hang on a thin platinum wire to the loop, so that the wire just touches the surface of the mercury in the dish beneath; a horseshoe magnet is then to be placed so that its poles shall be between the pendent wire. On making communication with the battery, the current passes along the loose platinum wire in order to complete the circuit, when the wire instantly acquires a vibratory motion. It is evident that the wire, which has a tendency to rotate round either pole of the magnet, but in opposite directions, cannot obey both forces; it therefore takes a situation between the two, being jerked forwards or backwards as the current is made to pass up or down the wire. This motion causes the wire to leave the mercury, breaking contact with the battery; the wire by its own gravity falling back again upon the mercury, contact is once more established, and thus an oscillating motion is maintained as long as the current passes.

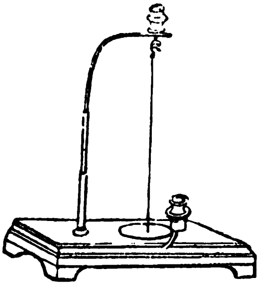

Fig. 78.

125. The foregoing apparatus of Mr. Marsh was modified

by Mr. Barlow, who regarded the wire as forming one radius of a circle, and that by the employment of a succession of radii it would give a rotatory motion. Fig. 79* is the apparatus of Mr. Barlow, arranged in the form of a star, so adjusted that one of its radii shall touch the mercury, the magnet and other parts being in the same condition as in the preceding experiment: on the connexion being made with the battery, the star immediately acquires a rotatory motion.

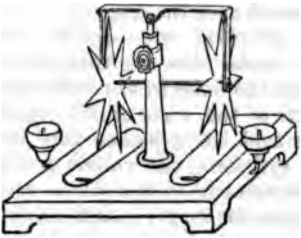
Fig. 79.

126. Unless the electrical power employed in this experiment be sufficient to throw out the one radius to such a distance as will bring another on to the surface of the mercury, the effect produced will be only equal to that of the single pendent wire. Therefore,

127. If a circular metallic disc (Fig. 80) is employed instead of the star, one part of the periphery is always in contact with the mercury; hence a less power of battery is sufficient to keep up the rotatory motion.

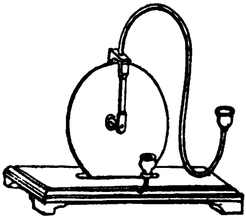
Fig. 80.

128. **Electro-dynamic Induction.**—We are indebted for most of the facts connected with this interesting and important branch of our present subject to Dr. Faraday, who, in 1831, discovered that whenever an electric current is made to pass through a wire, it induces in another wire held parallel to it a secondary current, which current, however, is always in an opposite direction to the inducing or primary current. Secondly, that when one pole of a magnet is introduced into a helical coil of wire, similar currents are induced in the wire of the coil. In both cases these currents are not permanent, but exist only at the time contact is made or the

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* *The figure* gives a double wheel of the stellar form, which acts in *the same manner as* the single wheel, but rather to better advantage.

magnet is introduced. Thirdly, when the current in the primary wire ceases to flow, or when the magnet is withdrawn from the coil, the secondary current is again produced, but now in an opposite direction. The following experiments will serve to illustrate the facts here mentioned.

129. Magneto-electric Induction Coil.—On a reel or bobbin, with a hollow axis of about an inch diameter, coil a few yards of insulated copper wire;* through holes made in the sides of the reel, pass the two ends of this, the first, or, as it is commonly called, primary wire; over this, coil in the same direction about 70 or 80 feet of a much thinner copper wire, also insulated; and let the ends of this wire be a yard or two in length, and, like the first coil, passed through two holes in the bobbin on the opposite side to those of the primary. If the thin wires are connected with the galvanometer (69), and a current of voltaic electricity is sent through the primary coil, the instant contact is made with the battery the needles of the galvanometer show by their deflection that a current passed through the thinner wire; that this current formed no part of that passing from the battery, is proved by the fact, that although the connexion with the battery is maintained, the needles are no longer influenced by it, showing that the current which caused their deflection existed only for a moment, and was produced simply by the induction caused by the primary current. If contact with the battery be now broken, the needles will be again deflected, but in an opposite direction to the former, thereby proving the change in the direction of the current.

On a similar bobbin, coil about 100 to 150 feet of the thin insulated wire: a less length of wire will do, but the effect is not so good; the ends being brought through the sides of the reel, and connected with the galvanometer, as in the former experiment. It is well in this case that some little distance should exist between the latter and the coil. If we now suddenly introduce into the hollow axis of the coil one pole of a bar magnet, the needles, by their deflection, show that a current has passed through the coil. Allow the magnet to remain in the latter until the needles of the galvanometer have returned to their original position; on quickly withdrawing the magnet, a second deflection occurs, but, as in the former experiment (with the battery), in a contrary direction to the first current.

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* Wire is said to be insulated, so far as voltaic electricity is concerned, when covered with silk or cotton; the object being to prevent the lateral conduction through the mass, instead of through the length of the wire.

130. By taking advantage of the two effects just noticed—viz., the induced currents due to the battery and coil, and those of the magnet—some very useful and interesting instruments have been constructed, under the name of electro-magnetic coil machines. These machines have undergone many modifications, but simply as to the mode of making and breaking contact with the battery and primary coil, the principle of action being the same in all. They may conveniently be divided into two classes—viz., those which require to be turned by hand, and those which are self-acting. The instrument (Fig. 81) of Dr. Bachhoffner was that first invented. It consists of a wooden reel with a hollow axis, within which is placed a bundle of insulated iron wire; the coil has two helices of covered copper wire, of different diameters and length, wound round it, independently of each other. By means of binding screws, the terminals of the primary coil of wire are united to the voltaic battery; but this union is alternately interrupted and restored by the multiplying wheel actuating the circular contact breaker. The two screws shown in front of the instrument are those connected with the secondary coil: if to these two wires are attached, dipping into two basins of water, the shocks from the induced current will be produced every time contact is made and broken with the battery. The intensity of this machine, when employed for medical purposes, may be modified by receiving the shocks, 1st, from the primary coil without the bundle of iron wire; 2nd, with the iron wires; 3rd, from the secondary coil without the bundle of iron wires; *and lastly, with it.*

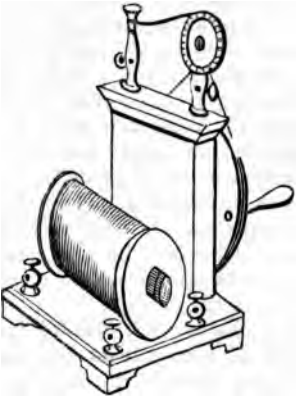

Fig. 81.

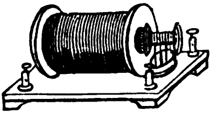

Fig. 82.

Self-acting Coil Machines (Figs. 82, 83, 84).—In the first of these, the small rotatory magnet (94) makes and breaks the battery contact; the bundle of iron wires becoming magnetic by the passage of the current through the primary coil, takes the place of the permanent horseshoe magnet, shown in the second figure. The second arrangement (Fig. 83) is decidedly preferable to the former, as it admits of the iron coil being withdrawn so as to modify the effects, which cannot be done with the first machine. The third instrument (Fig. 84) offers the same disadvantage as the first; but it has this superiority, that mercury is dispensed with, which at all times is a source of much annoyance in electro-magnetic experiments. The contact breaker in this apparatus is a tinned disc of iron, held by a spring over the axis of the bundle of iron wire. When the apparatus is in action, the disc is alternately attracted down by the bundle, or brought back by the spring consequent upon the downward motion of the former breaking the connexion with the battery.

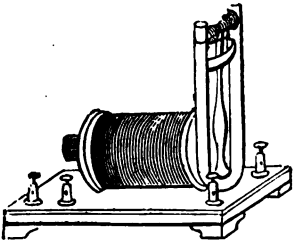

Fig. 83.

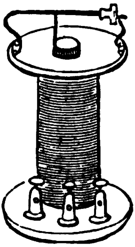

Fig. 84.

131. Ruhmkorff's Coil (Fig. 85) is a most important improvement on all previously existing instruments of this class. M. Ruhmkorff has succeeded, by a careful insulation of the secondary wire in its several convolutions, and also from the primary and bobbin, in producing an instrument the effects of which are most remarkable, as well as being of a highly philosophical character. The instrument consists of a reel, from twelve to fifteen inches in length, the ends of

which are formed of thick plate glass, well varnished: this is surrounded, as usual, by two wires, the secondary one being of great length, covered with silk and well varnished, each layer of coils being carefully insulated from its next in succession:* within the axis of the coil is placed a bundle of soft iron wires. The ends of the primary wire are connected with a self-acting contact breaker, very ingeniously contrived. The shocks from the instrument are most powerful and painful, and should never be received without great caution. When in operation, the secondary coil gives off a continuous stream of brilliant sparks, with a loud snapping noise; and were the means by which they are produced not seen by the spectators, they might readily be mistaken for sparks from an ordinary electrical machine. If the flame of a small spirit lamp be introduced between the opening in the wires of the secondary coil during the passage of the sparks, the latter may be made to pass through a much greater interval, the flame acting as an intermediate conductor, the effect of which is exceedingly beautiful, as the spark is seen distinctly passing from point to point and through the flame at the same time. The discharge, when taken *in vacuo*, either of the air-pump or the Torricellian vacuum, far exceeds in brilliancy, although not in distance, the common experiment of the electric aurora. When the discharge is taken between two brass balls in the exhausted receiver of an air-pump, a very beautiful effect is produced: one ball is surrounded by a beautiful purple halo,

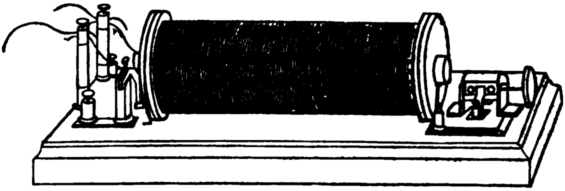

Fig. 85.

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* In order to increase the power of the apparatus, M. Fizeau conceived the idea of adding a condenser, the two plates of which being bent around each other, and separated by an insulating stratum of wax silk, communicating respectively with either end of the inducing wire, so as to become charged when the current is interrupted, and to be discharged when it is re-established, which greatly increases the power of the current, the discharge having the same direction as the current.—*De la Rive's Treatise*, vol. ii. page 29.

it a long luminous discharge occurs from the other;
een the two balls there exists also a non-luminous interval.
num wire can be made red-hot, the voltaic light obtained
een pieces of charcoal, and many other interesting expe-
nts may be effected by this beautiful apparatus.

2. **Magneto-electric Induction.**—
following simple yet instructive
ratus (Fig. 86) was the one by
h Dr. Faraday originally obtained
lectric spark by magnetic induc-
:—Wind round the middle of a
of soft iron about twenty or thirty
s of insulated copper wire: this
be so wound as to admit of the
passing between the limbs of the
net: to one end of the wire must
ldered a small disc of copper, the
end being brought to a point.
e two ends—namely, the disc and
oint—are so arranged that the
shall just rest upon or touch
ormer. If the uncovered ends of
bar or armature be brought in
ct with the two poles of a horse-
magnet, and one end is quickly
d a short distance to and from the pole which it covers,
t sparks will be seen to pass between the point and

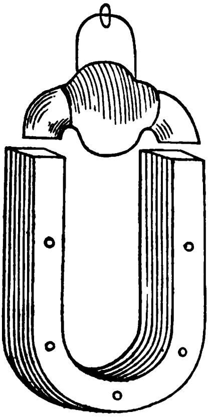
Fig. 86.

3. Soon after this fact was developed,
Pixii, of Paris, constructed an in-
ent, which consisted of a powerful
shoe magnet, mounted so as to admit
being made to rotate rapidly upon an
and immediately under a fixed arma-
surrounded by a coil of wire. By this
ine, brilliant sparks were obtained, by
ng the break in the current to occur
e surface of mercury. This appara-
as, however, quickly improved upon,
g rise to the instruments now to be described.

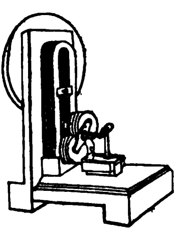
Fig. 87.

gneto-electrical Machines.—These machines differ from
lectro-magnetic machines (130) in having a permanent
et as the inducing agent. Two different forms are in use

in this country, one in which the magnet is placed horizontally, the other vertically, shown in Figs. 87, 88. The magneto-machine consists of a permanent horseshoe magnet, before the poles of which, by turning a multiplying wheel attached, a horseshoe bar of soft iron is made rapidly to rotate, on which is coiled a copper wire carefully insulated. The ends of this wire are connected either to two breaks dipping into their respective mercury cups, or by springs pressing on a contact break attached to the revolving armature. It is usual to supply two armatures, one with a long coil of thin wire, the other having a much shorter and thicker wire: the former is called the intensity, and the latter, the quantity armature.*

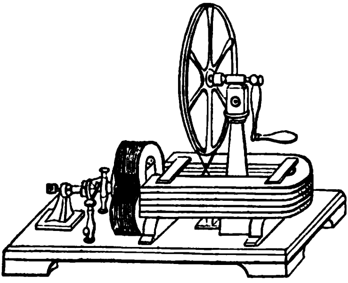
Fig. 88.

134. By these instruments all the usual effects of voltaic electricity on a small scale may be exhibited—such as the heating of platinum wire, the sparks between charcoal points, the production of electro-magnets, the magneto-electric spark, &c. These are best exhibited with the quantity armature—whilst the shock, the decomposition of water and of neutral salts, are most effectually carried out by the intensity armature.†

135. Magneto-electric Induction Machine (Fig. 89)—Is an instrument constructed by the late Mr. Francis Watkins, in which the permanent magnet is replaced by a large electro-magnet. The working of this instrument obviously requires the aid of a voltaic battery, by which means a very powerful magnetic influence is easily obtained, and hence an increased amount of induced action is produced upon the armature.

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* A very full description of the construction and uses of the vertical magneto-machine is given in the *Electrical Magazine* for January, 1837.

† Magneto-electric machines are now used in Birmingham, on a large scale, as a substitute for the voltaic battery in processes of electro-silvering and gilding. Machines of this class have been constructed by which *2¼ oz. of silver* per hour have been deposited.—Miller's *Elements of Chemistry, part i.* page 407.

The general effects obtained by this apparatus are of great energy and brilliancy.

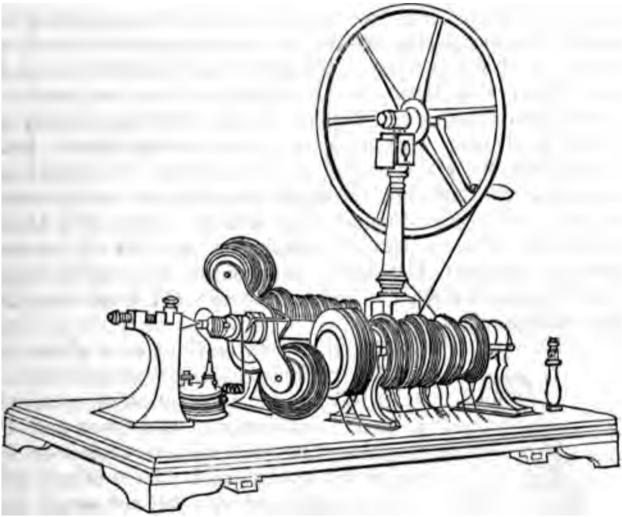

Fig. 89.

136. Dove's Differential Inductometer.—This instrument (Fig. 90) is formed of two similar hollow wooden cylinders, surrounded by exactly the same length and thickness of stout insulated copper wire: each primary coil is surrounded by a secondary coil of fine wire, of equal length and dimensions, wound upon a distinct wooden cylinder which passes over the primary coils. The apparatus is employed for

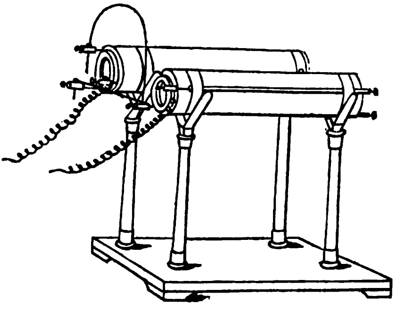

Fig. 90.

the purpose of estimating the comparative inducing effects produced by introducing within the hollow cylinder different kinds and forms of iron and steel. When the two secondary coils are so united that the current moves through them in opposite directions, the effects are necessarily neutralized, as proved by the free ends of the coil being attached to a galvanometer: this is no longer the case, if in one helix a bar of iron is placed. Owing to the vast superiority of a bundle of iron wire as a magneto-inducing agent, first pointed out by Dr. Bachhoffner, the operator is enabled to determine the number of wires necessary to compensate the effects of a given mass of steel or iron. Thus, Mr. Dove found that when a bar of forged iron was placed in one helix, it required 110 wires to establish the equilibrium: with tempered steel, 28, and with grey cold blast iron, 27 were sufficient.

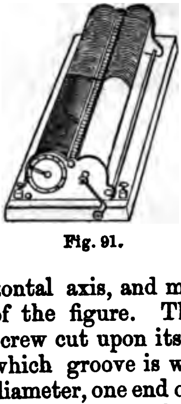

Fig. 91.

137. Rheostat is the name given by Professor Wheatstone to an instrument (Fig. 91) which he has invented, by which measured quantities of resistance may be introduced into the voltaic current, or by which the electro-motive force of any voltaic arrangement can be compared and measured. It consists of two cylinders, 6 inches long and 1½ in diameter, placed side by side, one being formed of wood and the other of brass: both are so mounted as to turn freely upon a horizontal axis, and may be turned by the handle shown in front of the figure. The wooden cylinder has a spiral groove or screw cut upon its surface, having forty turns to the inch, in which groove is wound a fine brass wire, $\frac{1}{100}$ of an inch in diameter, one end of which is attached to a binding screw fixed on the base board, the other being soldered to the opposite end of the brass cylinder, which is likewise in metallic connexion with the other binding screw. When the fine wire is wound round the wooden cylinder, and the apparatus forms part of the circuit, the current has to pass through the whole length of this wire; but on turning the handle of the brass cylinder, any portion of the wire may be wound off, and thus being in metallic communication with the former, the current has the

resistance diminished in proportion to the length of wire so transferred. The scale in front of the instrument enables the operator to read off the number of turns, or even fractions of a turn, thus transferred.

138. Resistance Coils.—These are simple coils of very fine insulated copper wire, $\frac{1}{200}$ of an inch in diameter, and are to be used in conjunction with the former instrument, when the electro-motive force is greater than the range of the Rheostat will govern. Professor Wheatstone employs six of these coils, two of 50 feet, the others having in their order 100, 200, and so on, up to 800 feet of wire. They are so arranged that one or all can be introduced into the circuit, and thus the resistance can be increased or diminished as the investigator may require.*

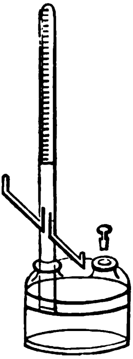
Fig. 92.

139. Voltameter.—This instrument, the invention of Dr. Faraday, is of the greatest importance as a measurer of the electro-chemical force of the voltaic battery. It has undergone many changes and modifications. Dr. Faraday's original instrument (Fig. 92) was a two-necked glass vessel: into one of the necks was fitted, by grinding, a glass tube closed at the top, and graduated into the cubic inch and fractional parts, the platinum electrodes being fused into the glass tube. In its present form, it consists of a cylindrical glass vessel (Fig. 93) cemented to a bottom of wood, passing through which are two stout wires well covered with the cement, and to which two plates of platinum are attached, the other ends of the wires terminating in mercury cups or binding

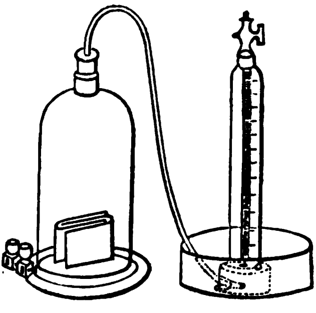
Fig. 93.

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* A description and mode of working these instruments will be found in the *Philosophical Transactions*, 1843.

screws outside the vessel: to the neck of the glass cylinder is attached, by a screw joint, a pewter tube, terminating in the vessel holding the cubic-inch measurer.

140. Fig. 94 is another arrangement of this instrument. By the introduction of a porous diaphragm dividing the vessel into two portions, having a platinum plate on either side, the gases, oxygen and hydrogen, resulting from the decomposed water are separately obtained, and may be measured and estimated accordingly. This form of the apparatus is very useful in the laboratory, for eliminating small quantities of these gases for experimental purposes.

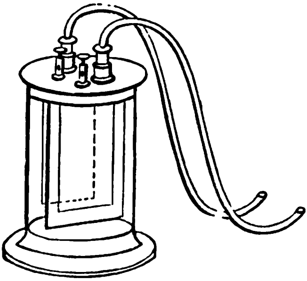
Fig. 94.

141. The laws upon which this instrument is founded were deduced by Dr. Faraday in prosecuting his researches in electro-chemistry, and are as follows:—1st. That the chemical power of the battery is in direct proportion to the absolute quantity of electricity which passes. 2nd. That the quantity decomposed (*i. e.* of water in the voltameter) is exactly proportionate to the quantity of electricity which has passed. 3rd. That for a constant quantity of electricity, whatever the decomposing conductor may be—whether water, saline solutions, acids, fused bodies, &c.—the amount of electro-chemical action is always a constant quantity, *i. e.* would always be equivalent to a standard chemical effect, founded upon ordinary chemical affinity. By way of illustration, let us suppose that during the action of the battery, the voltameter has given off 68 cubic inches of the mixed gases,* equal to 9 grains of water, *i. e.* hydrogen 1 + oxygen 8. Then it will be found that to produce that quantity of gas—or, which amounts to the same thing, to decompose 9 grains of water,—32 grains of zinc have been dissolved, which have united with 8 grains of oxygen, forming 40 grains of oxide of zinc in the battery

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* The exact volume at 60 F. and 30 in. Bar. is oxygen 23·3, hydrogen 46·6 cubic inches.

the same quantity of electricity, if it had been trans- ed through fused chloride of silver, would have decom- l 144 grains, yielding 36 of chlorine and 108 of r.

2. Harris's Hydrostatical Electrometer.—By the aid is ingeniously-contrived apparatus (Fig. 95), we are led to investigate the re of the attractive and lent forces of electricity ting between two con- ing surfaces. It con- of a balance-wheel sup- d on friction rollers, g a light index of wood, ing to the graduated bove: over a groove in wheel passes a silk thread hed to one of silver, the end of which communi- with the upper disc, t to the silver end is nded a short cylinder of ,partly floating in water, g as a counterpoise to pper disc; beneath this other disc, which can be ted or depressed, so as to t of its being placed at required distance from immediately over it: discs are formed of d wood, and are quite free points or sharp edges. djust the instrument, the r-vessel must be lowered or elevated until the index ls in the middle or zero of the arc. In using this in- nent, supposing the force to be one of attraction, the upper is insulated by connecting it by a fine wire with its silver d; but when a repulsive force forms the subject of tigation, then the disc is allowed to hang by its insulat- silk above. In either case, the forces are shown by the ment of the index on either side of the zero point.

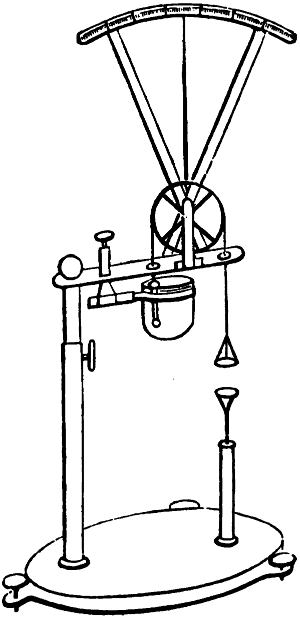

Fig. 95.

143. Fig. 96, called by Sir W. S. Harris the Scale-beam Electrometer, differs from the Hydrostatic (95) in having a common balance instead of the wheel-work of the former, the force exerted being estimated in grains placed in either scale-pan.

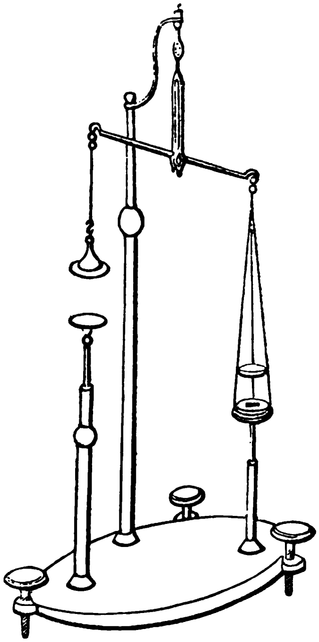

Fig. 96.

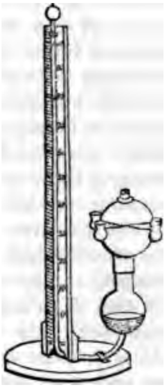

Fig. 97.

144. Harris's Thermo-electrometer (Fig. 97) consists of an air thermometer, through the bulb of which is passed a platinum wire, varying from $\frac{1}{50}$ to $\frac{1}{100}$ of an inch in diameter, and about three inches in length, the ends terminating in two mercury cups: the top of the bulb is supplied with a screw valve, for the purpose of adjusting the height of the coloured fluid to the zero point of the scale, before commencing the experiment. On including the cups of the thermometer in the circuit of a discharge from a Leyden jar or battery, the temperature of the wire is raised by the passage of the charge: this causes the air in the bulb to expand, which *pressing* upon the fluid, causes it to ascend, the height

being observed on the graduated scale. It is found by Sir W. S. Harris, that the height to which the fluid rises is, *cæteris paribus*, as the square of the quantity of electricity discharged through the wire.

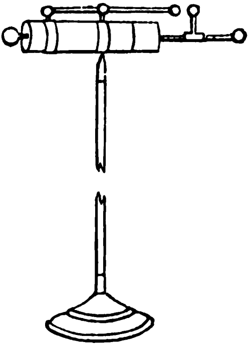

Fig. 98.

145. Unit Jar.—This instrument, the invention of Sir W. S. Harris, is employed to measure the relative quantity of electricity conveyed into a jar or battery. It is simply a small insulated Leyden jar, to the outside coating of which is fixed a wire, extending beyond the jar, and terminating in a ball. In connexion with the inner coating is another ball, sliding upon the rod of the jar, and is so arranged that it may be placed at different distances from the outside coating. The inside of the jar is connected with the electrical machine, and the outside with the jar or battery to be charged. Whilst the unit jar is receiving its charge, it is also communicating to the battery a quantity of electricity equal to that which it receives. As soon as the intensity of the charge in the former is sufficient to overcome the resistance between the two balls, a discharge occurs, without in any way affecting the condition of the battery: hence the number of the discharges of the small jar becomes the measure of the amount of force in the battery.

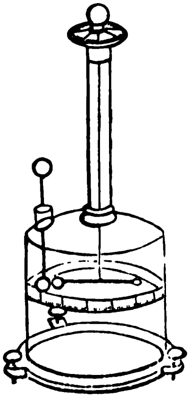

Fig. 99.

146. Coulomb's Torsion Balance—Is an instrument for measuring very small amounts of electric force. A needle, formed of a thin stem of shelllac, is suspended either by a fibre of raw silk, a thread of glass, or a very fine silver wire, within a cylinder of glass, the support being carried up through a tube of glass attached to the cover of the instrument, and is there

fixed to a pivot carrying an index working in a brass cap, the circumference of which is divided into degrees. To one end of the lac needle is fixed a disc of paper covered with gold leaf, and passing through the cover is another ball freely insulated; around the inside of the glass cylinder, and in a line with the ball and needle, is pasted a paper circle divided into degrees, the zero point being the centre of the stationary ball. When the ball has received a charge of electricity, a mutual repulsion occurs between it and the paper disc, proportionate to the intensity of the communicated electricity, by which the suspending medium becomes more or less twisted: the force is measured by the power of torsion exerted on the thread or wire. According to the experiments of Coulomb, electricity follows the same law as gravitation—viz. "in the inverse ratio of the squares of the distances of the acting bodies."

147. Gutta Percha as an Insulator.—"A good piece of gutta percha will insulate as well as an equal piece of shell-lac, whether it be in the form of sheet, rod, or filament; but being tough and flexible when cold, as well as soft when hot, it will serve better than shell-lac in many cases when the brittleness of the latter is an inconvenience."

"Thus, it makes very good handles for carriers of electricity in experiment on induction; not being liable to fracture in the form of either band or string, it makes an excellent insulating suspender; a piece of it in sheet makes a most convenient insulating basis for anything placed on it. It forms excellent insulating plugs for the stems of gold-leaf electrometers, when they pass through sheltering tubes, and larger plugs form good insulating feet for electrical arrangements; cylinders of it, half an inch or more in diameter, have great stiffness, and form excellent insulating pillars."—*Phil. Mag.*, March, 1848.

THE END.

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LIST OF PRICES.

Fig.	1.	Stand with suspended Paper Cylinder,	7*s*. 6*d*.
„	2 and 3.	Gold-leaf Electrometer,	16*s*.
„	4.	Insulated Conductor,	5*s*. 6*d*. to 16*s*.
„	6.	Electrophorus,	10*s*. 6*d*. to 42*s*.
„	7.	Electrical Condenser,	18*s*., 30*s*., 63*s*.
„	8.	Cylinder Electrical Machine,	18*s*. to £10 10*s*.
„	9.	Plate „ „	42*s*., 63*s*., to £26 5*s*.
„	10.	Hydro-Electric Machine,	£15 15*s*. to £100.
„	11.	Volta's Pile,	15*s*.
„	12.	Cruikshank's Voltaic Battery,	25*s*. to 70*s*.
„	13.	Daniell's „ „	4*s*. 6*d*. to £5 5*s*.
„	14.	Grove's „ „	10*s*. to £10 10*s*.
„	15.	Smee's „ „	10*s*. to £5 5*s*.
„	16.	Bunsen's „ „	10*s*. 6*d*. to £3 3*s*.
„	17.	Grove's Gas „ „	£4 4*s*.
„	18.	Zinc and Copper Plates,	3*s*. 6*d*. to 12*s*. per doz.
„	*20.*	*Five Pairs* „	10*s*.

Fig. 21. Single Pair of Bismuth and Antimony, 4*s.* 6*d.*
„ 23. Large Thermo-Battery, £3 3*s.*, £4 4*s.*, £4 14*s.* 6*d.*
„ 24. Melloni's „ 25*s.*, 31*s.* 6*d.*
„ 25. Natural Magnets, 2*s.* 6*d.*, 5*s.*, and £5 5*s.*
„ 26. Bar Magnets, in pairs, 1*s.*, 2*s.* 6*d.*, 3*s.* 6*d.*, 5*s.*, to 42*s.*
„ 27. Horse-shoe Magnets, 6*d.*, 1*s.*, 2*s.*, 5*s.*, to £5 5*s.*
„ 28. Magnetic Compass, 3*s.*, 5*s.*, 10*s.*, to £2 2*s.*
„ 29. „ „ with Floating Card, 3*s.* 6*d.*, 4*s.* 6*d.*, 5*s.*, to £2 2*s.*
„ 30. Dipping Needle, 7*s.* 6*d.*, 12*s.*, 18*s.*
„ 31. Needle for Suspension, 2*s.* 6*d.*
„ 34. Babbage's Apparatus for Induction, £3 3*s.* & £5 5*s.*
„ 35. „ „ £4 4*s.* & £7 7*s.*
„ 36. Sturgeon's Magnetometer, £2 2*s.*
„ 37. Large Electro-Magnet for Faraday's Experiments.
„ 38. Oersted's Apparatus, with Adjusting Point, 12*s.* 6*d.*
„ 39. Improved ditto to Show the Dip, 18*s.*
„ 40. Small Voltaic Battery with Needle, 10*s.* 6*d.*
„ 41. Simple Oersted's Apparatus.
„ 42. Delicate Galvanometer, 42*s.* and 63*s.*
„ 43. Tangent, £27 10*s.*
„ 44. Seebeck's Thermo Apparatus, 8*s.* 6*d.*, 10*s.* 6*d.*
„ 45. Rectangular Wire Frame and Stand, 25*s.*, 31*s.* 6*d.*
„ 46. De la Rive's Floating Battery, 5*s.* 6*d.*
„ 48. „ „ 5*s.* 6*d.*
„ 49. Suspended Flat Spiral Coil, 7*s.* 6*d.* and 10*s.* 6*d.*
„ 51. Insulated Coil for Magnetising Needles, 2*s.* 6*d.*
„ 52. Primary and Secondary Coil for Induction, 31*s.* 6*d.* and 42*s.*
„ 55. Electro-Magnet and Keeper, 3*s.* 6*d.* to £3 3*s.*
„ 56. Barlow's Globe, £3 13*s.* 6*d.* and £4 14*s.* 6*d.*

Fig. 57. Ritchie's Rotating Magnet, 10*s*., 12*s*., and 15*s*.
„ 58. Electro-Magnetic Mill, 32*s*.
„ 59. Large Rotating Magnet, 30*s*.
„ 60. Electro-Magnetic Machine with Vertical Magnets, £6 6*s*., £8 8*s*., £10 10*s*.
„ 61. Electro-Magnetic Machine, with Horizontal Magnets, £16 16*s*.
„ 62. Electro-Magnetic Pendulum, £5 5*s*. and £9 9*s*.
„ 64. Electric Telegraph, £2 2*s*. to £5 5*s*.
„ 68. Reotrope or Current Inversor, 12*s*.
„ 71. Faraday's Rotating Wire, 10*s*.
„ 72. „ „ 25*s*.
„ 73. Rotating Spiral Coils, 24*s*.
„ 74. Barlow's Rotating Cylinders, 31*s*. 6*d*.
„ 75. Rotating Magnets about a Vertical Wire, 21*s*., £1 11*s*. 6*d*.
„ 76. Rotation of a Magnet about its own Axis, 21*s*., 42*s*.
„ 77. Ampère's Rotating Battery, 24*s*.
„ 78. Marsh's Vibrating Wire, 7*s*. 6*d*.
„ 79. Double Stellar Wheel, 18*s*., 24*s*.
„ 80. Rotating Circular Metallic Disc, 15*s*.
„ 81. Bachhoffner's Coil Machine, £3 3*s*.
„ 82. Coil Machine with Rotating Magnet, 18*s*. and 21*s*.
„ 83. Ditto, larger, £1 11*s*. 6*d*.
„ 84. Ditto, with Vibrating Break, 16*s*., 21*s*.
„ 85. Ruhmkolff's Coil, £7 7*s*. and £10 10*s*.
„ 86. Pennant's Compound Magnet, with Electro-Magnetic Armature.
„ 87. Magnetic Inductive Machine, £10 10*s*. & £12 12*s*.
„ 88. „ „ £10 10*s*. to £12 12*s*.
„ 89. Ditto, with Electro-Magnet, £8 8*s*. to £31 10*s*.
„ 90. Dove's Differential Inductometer, £5 5*s*.

Fig. 91. Wheatstone's Rheostat, £3 13*s*. 6*d*.
„ 92. Faraday's Voltameter, 21*s*.
„ 93. Voltameter with Bent Tube, £2 12*s*. 6*d*. to £5 5*s*.
„ 94. Ditto, with Diaphragm and Two Bent Tubes, £2 2*s*. and £3 3*s*.
„ 95. Harris's Hydrostatical Electrometer, £10 10*s*.
„ 96. „ Scale Beam ditto, £6 6*s*. and £8 8*s*.
„ 97. „ Thermo ditto, £1 11*s*. 6*d*., £2 12*s*. 6*d*.
„ 98. „ Unit Jar ditto, 18*s*. and 21*s*.
„ 99. Coulomb's Torsion ditto, £2 2*s*., £2 12*s*. 6*d*.

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Ditto ditto ditto, with Tangent Screw Adjustments		20	0	0
Five-inch Theodolite		16	16	0
Ditto, divided on Silver, with Tangent Screw Adjustments		24	3	0
Six-inch Theodolite		18	18	0
Ditto, divided on Silver to 20 Seconds, with Tangent Screw Adjustments		29	8	0
Ditto ditto, with 2 Telescopes		38	0	0
Seven-inch best Theodolite		34	13	0
Ditto ditto, with 2 Telescopes		44	2	0
Five-inch best Transit Theodolite		29	8	0
Six-inch ditto ditto.		34	13	0
Seven-inch ditto ditto		40	19	0
Everest Theodolite, 4-inch		21	0	0
Ditto ditto, 5-inch		25	4	0
Small Level, with Stand, for drainage		6	6	0
Ten-inch Y Level		9	9	0
Fourteen-inch Y Level with Compass		14	14	0
Elliott's improved Dumpy Level		14	14	0
Ditto ditto, with Compass		16	16	0
Ditto ditto, 14-inch		15	15	0
Ditto ditto ditto, with Compass		17	17	0
Ditto, ditto, extra large		21	0	0
Circumferenters	from 5*l.* 15*s.* 6*d.* to	15	15	0
Prismatic Compass	3*l.* 3*s.* to	8	13	6
Pocket Sextant		4	4	0
Ditto, with Telescope		4	14	6
Ditto, ditto, and Supplementary Arc		5	15	6
Optical Square		1	1	0
Pentagraphs	5*l.* 15*s.* 6*d.* to	10	10	0
Eidograph		10	10	0
Transit Instruments	16*l.* 16*s.* to	73	10	0

		£	*s.*	*d.*
Cross Staff	10*s.* 6*d.* to	0	16	0
Ditto, with Compass and Screw Staff	2*l.* 2*s.* to	2	12	6
Miners' Compass	5*l.* 5*s.* to	18	18	0
Circular Protractors, with Verniers	3*l.* 13*s.* 6*d.* to	7	17	6
Metal Circular and Semicircular Protractors	10*s.* 6*d.* to	5	5	0
Level Staff, 14-feet, portable	from 2*l.* 15*s.* to	3	0	0
Ditto, 17-feet		4	14	6
Gravatt's Level Staff	3*l.* 3*s.* to	4	4	0
Papers for Level Staves	per foot	0	0	2
Ditto, in sets, for 14-feet Portable Staff		0	3	0
Chain, 66-feet	10*s.* to	0	18	0
Standard Chains	3*l.* 3*s.* to	5	5	0
Arrows, set		0	2	0
Tapes, 33-feet to 100-feet	6*s.* to	1	1	0
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Four-inch Metal Sextant, divided on Silver		9	9	0
Five-inch ditto ditto		12	12	0
Six-inch ditto ditto		13	13	0
Seven-inch ditto ditto		15	15	0
Eight-inch ditto ditto		16	16	0
Ditto ditto ditto, with double frame		17	17	0
Quadrant	2*l.* 12*s.* 6*d.* to	6	6	0
Artificial Horizon	2*l.* 12*s.* 6*d.* to	4	14	6

		Brass.			German Silver.		
		£	*s.*	*d.*	£	*s.*	*d.*
Proportional Callipers, 12 inches		2	0	0	2	12	6
Ditto ditto, 9 inches		1	14	0	2	2	0
Proportional Compass, 12 inches		3	0	0	3	13	6
Ditto ditto, 9 inches		2	5	0	3	3	0
Ditto ditto, 6 inches		1	10	0	2	0	0
Ditto ditto, ditto, with Adjustment		2	0	0	2	10	0
Whole and half ditto		0	18	0	1	4	0
Triangle ditto		0	18	0	1	4	0
Tube Compass		1	15	0	2	5	0
Ditto, Needle Points		1	18	0	2	8	0
Tube Beam Compass		2	0	0	2	12	6
Pocket Turn-in Compass		1	6	0	1	16	0
Ditto ditto, with handles		1	10	0	2	2	0
Ditto ditto, ditto, and Bars		2	2	0	2	12	6
Pillar Compass, with divided Sheath		1	11	6	2	2	0
Napier Compass					2	2	0
Pocket Dividers, with Sheath		0	8	0	0	10	0
Best double-jointed Compass		0	15	0	1	1	0
Ink Pencil, and Wheel Legs for ditto	each	0	5	6	0	7	6
Lengthening Bar		0	5	0	0	7	0
Hair Divider		0	10	0	0	13	0
Plain Divider		0	6	0	0	8	0
Tate's Bow		1	4	0	1	11	6
Double-jointed Bowpen and Bowpencil	each	0	10	6	0	13	0
Ditto ditto, Needle-pointed	each	0	12	0	0	15	0

		Brass.			German Silver.		
		£	*s.*	*d.*	£	*s.*	*d.*
Hair Bow Divider		0	9	0	0	12	0
Large Needle Bows	each	0	15	0	1	1	0
Spring Bowpen and Pencil	each	0	8	6	0	8	6
Spring Divider		0	7	6	0	7	6
Ivory Handle Drawing Pen		0	5	0	0	5	0
Ditto, ditto, jointed		0	5	6	0	7	0
Ebony ditto		0	3	6	0	3	6
Double Pen		0	10	6	0	10	6
Six Wheels and Box		0	6	6	0	6	6
Six Pens and one Handle		1	6	0	1	6	0
Tracer		0	2	6	0	2	6
Crow Quill Holder		0	3	0	0	3	0
Needle Holder		0	2	6	0	3	0
Knife		0	1	6	0	1	6
Sector jointed Compass, 4½, 5 or 6 in.		0	10	0	0	15	0
Divider		0	6	0	0	8	0
Ink, Pencil, and Wheel Legs	each	0	5	6	0	7	6
Bar		0	5	0	0	7	0
Bowpen and Bowpencil		0	12	0	0	16	0
Marlow Compass		0	9	0	0	13	0
Divider		0	4	6	0	6	6
Ink and Pencil Legs		0	9	0	0	13	0
Bar		0	4	6	0	6	6
College Compass		0	7	0			
Ink and Pencil Legs		0	7	0			
Divider		0	3	6			
Ink and Pencil Bows		0	7	0			
Steel Joint Compass, with Pen and Pencil Legs		0	7	6			
Divider		0	2	6			
Bowpen and Pencil		0	6	0			
Drawing Pen		0	2	0			

Case of Instruments, as supplied to the Royal Military Academy		2	12	6
Ditto, as supplied to the College of Civil Engineers at Putney		3	10	0
Ditto, as supplied to King's College, London		2	15	0
Ditto, as supplied to the College, Cheltenham		3	3	0
Ditto, as supplied to the Cadets at Addiscombe, 3*l.* 3*s.*, 3*l.* 13*s.* 6*d.*, and		4	4	0
Magazine Cases of Instruments made of Brass, German Silver, or Silver, from 10*l.* 10*s.* to		50	0	0
Sector	6*s.* to	1	1	0
Marquois Scales, Boxwood		0	12	0
Ditto, Ivory		2	12	6
Ditto, German Silver		3	13	6

		£	s.	d.
Ivory Plotting Scales, 12 inches		0	10	0
Ditto ditto, 6 inches		0	5	0
Ditto Offset Scales, 2 inches		0	2	6
Ditto Architect's Scales, 12 inches		0	13	0
Ditto ditto, 6 inches		0	7	0
Ditto Protractor, 12 inches		1	10	0
Ditto ditto, 6 inches		0	6	0
Ditto Parallel Rule, Brass Bars		0	4	6
Ditto ditto, German Silver Bars		0	6	0
Ditto Pocket Rules	4*s.* 6*d.* to	1	11	6
Slide Rules		0	5	0
Routledges' Slide Rule, with Book		0	9	0
Hawthorn's ditto, with Book		0	12	0
Box Plotting Scales, 12 inches		0	4	0
Ditto Offsets		0	1	6
Ditto Architect's Scale		0	6	0
Ditto Pocket Rules	2*s.* 6*d.* to	0	14	0
Ebony Parallel Rule, 4*d.* per inch.				
Rolling Parallel Rules, 1*s.* per inch.				
Ditto ditto, with Ivory Edges, 1*s.* 8*d.* per inch.				
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Beam Compasses	1*l.* to	5	5	0

Twelve-inch Achromatic Telescope	15*s.* to	1	11	6
Eighteen-inch ditto	1*l.* 1*s.* to	2	2	0
Twenty-four-inch ditto	2*l.* 2*s.* to	3	3	0
Thirty-six-inch ditto	4*l.* 4*s.* to	5	5	0
Twelve-inch Portable Achromatic Telescope	1*l.* 11*s.* 6*d.* to	2	2	0
Eighteen-inch ditto ditto	2*l.* 2*s.* to	2	12	6
Twenty-four-inch ditto ditto	2*l.* 12*s.* 6*d.* to	3	3	0
Military Telescope, in Leather Case and Strap		3	10	0
Naval Telescopes	from 1*l.* 4*s.* to	6	6	0
Thirty-inch Astronomical Telescope, on Stand		12	12	0
Forty-five inch ditto ditto ditto, 2¾ aperture		25	4	0
Ditto ditto ditto, 3¼ aperture		42	0	0

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